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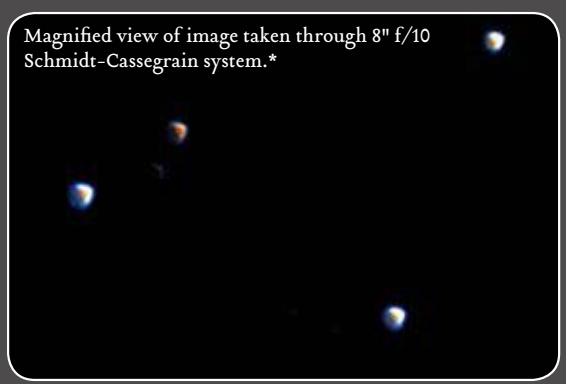

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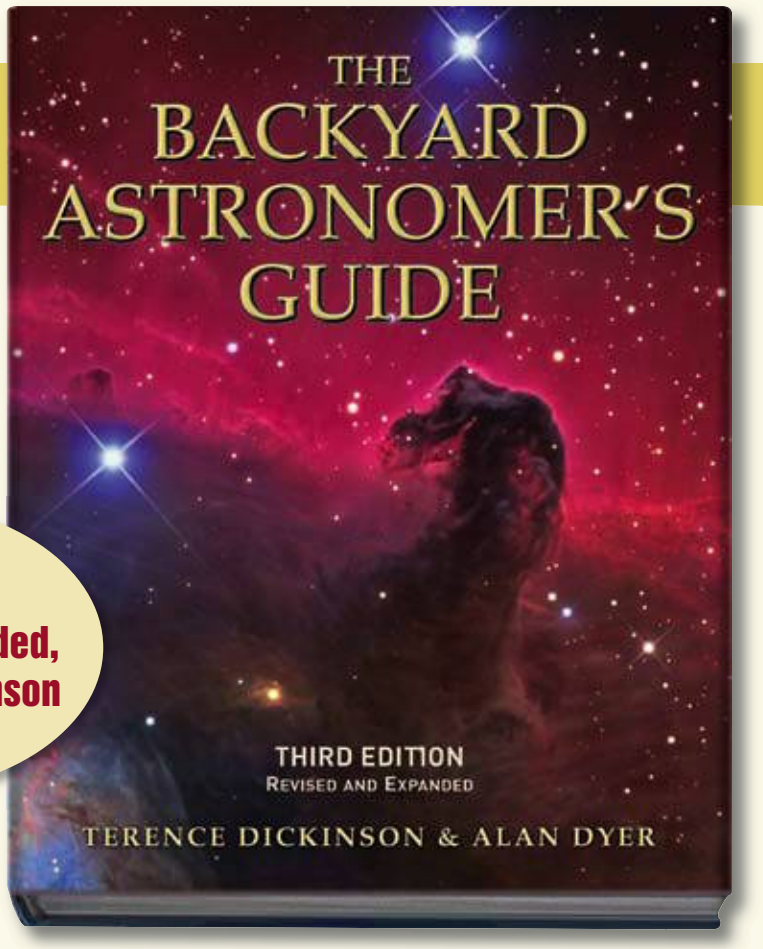

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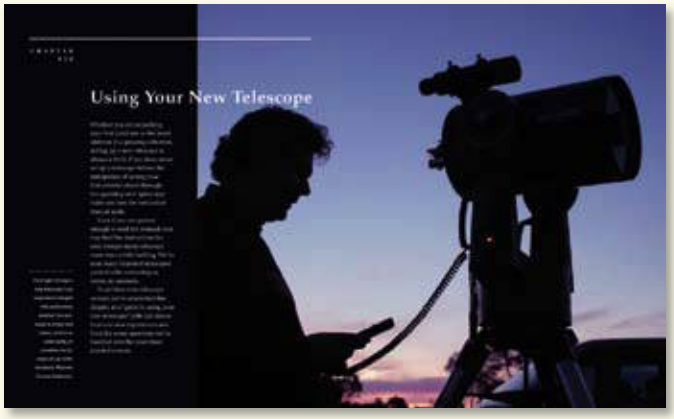

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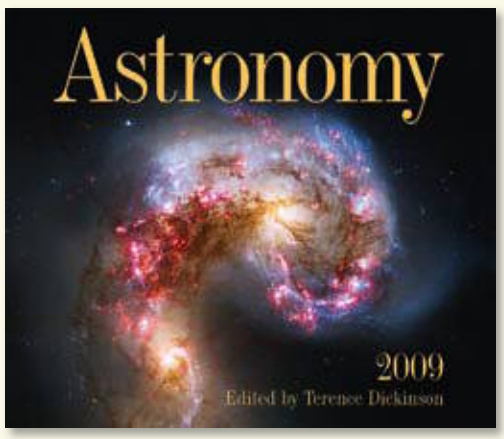

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Astronomy November 08

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This month in *Astronomy*

The hunt for super-Earths

by David J. Eicher

Astronomers discovered the first extrasolar planet in 1992. Sixteen years later, the number of planets known outside our solar system has grown to nearly 300. Most of the planets found thus far are really massive. The big ones are easier to detect through their pull on parent stars or blocking a portion of the star's light. Most of the exoplanets found thus far are similar in mass to Jupiter and Saturn, with a few in the range of Neptune.

Now the search is becoming far more interesting. In his story "Are super-sized Earths the new frontier?" Contributing Editor Ray Jayawardhana, an astronomer at the University of Toronto, updates us on the latest word in exoplanet searches.

The high-precision Doppler method of detecting shifts in the velocities of spectral lines in a star's light has enabled astronomers to hunt for smaller prey, Jayawardhana explains. In 2005, scientists discovered the first "super-Earth," a planet with 7.5 times Earth's mass, orbiting the star Gliese 876.

Last year, Stephane Udry of the Geneva Observatory and his colleagues raised the stakes when they found two super-Earths orbiting Gliese 581. One planet in this system has a mass that may be as small as five Earths, while the other weighs at least 8 times Earth's mass.

Another star has given up its secret of hiding a small planet. In 2008, Ignasi Ribas of the Institute of Space Sciences in Spain detected a planet with 5 times Earth's mass orbiting the star Gliese 436. And astronomers discovered a very cool, distant super-Earth by gravitational microlensing, this one orbiting a star only 20,000 light-years away.

"Even though only a handful of super-Earths have been identified so far, many researchers think they are more common than gas giants," writes Jayawardhana. The planets probably come in two types: watery, icy worlds, and rocky, earthlike ones. Jayawardhana explains how the search for worlds resembling large Earths will accelerate over the coming months and will undoubtedly lead to some fascinating discoveries.

In "Are these space rocks from Mercury?" astronomer Thomas Burbine of Amherst College reviews the intriguing possibility that angrites, a rare class of meteorites, may have originated from the innermost planet. Unlike most space rocks, angrites contain ample aluminum- and titanium-rich pyroxenes and calcium-rich olivines. Their sodium-poor composition hints that they formed oddly close to the Sun, and their texture is reminiscent of decompression and cooling like that which occur along thrust faults on Mercury. The question then arises: Are angrites from Mercury much rarer than meteorites from the Moon or from Mars?

Burbine's story explores the possibilities and places all the evidence in plain context. He ties the MESSENGER mission results coming from Mercury to the solution, suggesting that data from that spacecraft will probably resolve the question. Although pieces of evidence both for and against angrites originating from Mercury are compelling, in the end, Burbine simply states, "I will keep an open mind until I see the MESSENGER results." This compelling mystery may be with us for a while.

Yours truly,

David J. Eicher
Editor

Astronomy

Volume 36, Number 11

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The Milky Way's collision course

In "Our galaxy's date with destruction" (June 2008), the author presents a dire picture of our distant future. However, I'm confused. The article implies that a collision is inevitable. However, the galaxy merger simulation on page 32 shows the two galaxies approaching each other then drawing apart. If the mutual gravitational attraction is so powerful, why don't they merge on the first pass? — **Jared Collard,** Fairfield Glade, Tennessee

The two galaxies are not actually headed straight for each other, like trains on the same track. Instead, they are orbiting a common center of gravity, like the members of a binary star system.

Early in the merger, the orbits are quite large. With each encounter, the galaxies lose a bit of angular momentum, and their orbits tighten. At some point, they do collide and meld into each other. But it takes a few passes before the "big crunch" finally comes. — **Thomas J. Cox,** Harvard-Smithsonian Center for Astrophysics, Cambridge, Massachusetts

Heavenly news

In an age when we are bombarded constantly with reports of strife and violence, it is refreshing to have magazines like yours that show a much different side of reality. *Astronomy* and other magazines like it help inspire readers young and old to look to the heavens — not just for their beauty, but also as a symbol of hope for humanity in troubled times. If only we would forget our petty squabbles and work together to make the world a better place, we could truly reach for the stars. — **Herman Nacinovich,** Gulgong, Australia

What is a moon?

It seems that every natural satellite circling a planet is called a "moon" regardless of size or shape, like those two little dirt balls whizzing around Mars. Should not "moons" be designated according to an object's size? Surely, there must be better nomenclature than "moonlet" to distinguish a large moon from a tiny one. — **Jared Collard,** Fairfield Glade, Tennessee

A lot of debris swirls around planets, from small rocks down to fine dust, but nobody calls these objects moons. And every object orbiting a planet is considered a satellite. But which ones get to be called moons?

There is no universal rule for what body should be called a moon. Astronomers frequently use the informal term "moonlet" to describe small bodies orbiting within a planet's ring systems (as at Saturn), or small bodies orbiting other small solar system bodies, such as asteroids. — **Daniel Pendick,** Associate Editor

Anniversary wishes

I'll not be the first nor the last to offer congratulations on the "*Astronomy* at 35" special issue (August 2008). The photos and the sketches are the highlights of the issue! — **Jim Olsen,** Bethesda, Maryland

Astronomy's amazing progress

After reading Richard S. Ellis' "Quest for the first galaxies" (March 2008), I couldn't help but feel amazed at how far we've come. To think that just 85 years ago, we thought the entire universe was solely our Milky Way Galaxy. Now we're studying galaxies billions of light-years away. We know so much, but astronomers could make another amazing discovery that changes how we look at the world — and the entire universe. — **Jeffrey Mara,** Concord, Massachusetts

When I first subscribed to *Astronomy* in 1976, I never thought that I would still be a subscriber in 2008! I remember the first issue I received, a special bicentennial edition featuring the Viking Lander on Mars. What a great magazine. I was instantly hooked.

I have every issue of *Astronomy* since I originally subscribed. It is interesting to see how our understanding of the heavens has changed over the last 30 years! — **Ernest Armstrong,** Norco, California

As galaxy NGC 2207 merges with smaller galaxy IC 2163, they orbit a common center of gravity. NASA/Hubble Heritage Team (STScI)

Corrections

In August 2008's "Ask Astro" (page 75), the answer to "Would astronauts on the Moon observe Earth occulting background stars?" incorrectly states that glare from sunlight diffusely reflected off the lunar surface dilates the pupils of the eyes. Light actually constricts pupils, not dilates them.

In "The coming solar super storm" (September 2008), three errors were created during the editorial process that were not the fault of author Steve Odenwald. On page 35, it states that protons, not CME, produced the aurorae in 1859; this is untrue. On page 39, "sudden even upsets" should be "single event upsets." Also on page 39, the event that led to satellite outages and losses totaling nearly $3 billion was in fact Cycle 23, not 22. We regret the errors. — ***Astronomy* Editors**

We welcome your comments. Send letters to Astronomy *Letters, P. O. Box 1612, Waukesha, WI 53187; e-mail to letters@astronomy.com. Please include your name, city, state, and country. Letters may be edited for space and clarity.*

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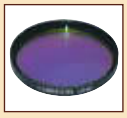

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Strange Universe

by Bob Berman

A piece of π

Intelligent beings throughout the galaxy remain obsessed with 3.14.

Ever "chew on" a portion of π? It's not a piece of cake. Pi has obsessed and tortured minds for centuries. This Greek letter, of course, represents the relationship between a circle and its diameter. It's certainly known by smart aliens throughout the universe, since disks and spheres are everywhere.

Pi is a rock-solid "word" in the extraterrestrial lingua franca. Other numbers that tattooed Andromedan school-kids have memorized no doubt include the four-to-one mass ratio of hydrogen to helium, the speed of light, and the location of the nearest major galaxy (us) sitting dreamily 13° from the milky "Andromeda Way" crossing their sky.

The Old Testament repeatedly expressed the pi ratio as exactly three: A round altar (in 1 Kings 7:23 and 2 Chronicles 4:2) is said to be "ten cubits from edge to edge and 30 cubits around." (A more correct circumference figure would have been 31½, but maybe they were seriously rounding off.) Jump ahead a half millennium to Archimedes, and we get a big official improvement to 3.1418.

Still no cigar. Pi is fascinating because it never evens out or ends. My 18-year-old daughter memorized its value to 75 decimal places. I went even further after a friend gave me a "Pi Pan" dish with 87 places inscribed around its edge. This neurosis-inducing item beckons daily. How far can you go? If you're obsessive — and unemployed — you can probably recite at least the first six digits. All I can recall is 3.14159265358979323846264338 327950288419716939937510582097494459 23078164. I'll mercifully stop there.

A wonderful feature of this perfectly random number pattern is that it's accurately computed using a simple and interesting equation: π precisely equals 4 multiplied by 1 – 1/3 + 1/5 – 1/7 + 1/9 – 1/11 + 1/13 and on and on. Astoundingly simple, and the more of these fractions you include, the greater the accuracy.

Einstein seems to have been the first to point out that rivers obey pi. The ratio of a river's straight-line distance from source to sea, when divided into its loopy path over the ground, is roughly equal to π.

Rivers acquire a meandering path because any small curve creates faster currents on the outer edge, where erosion then carves out a sharper bend. This in turn produces an even faster flow and accelerated material loss, since the mass of earth a river carries away is proportional to the sixth power of water speed.

So a river's bend keeps sharpening. But a natural process limits this watery desire toward circularity: Too much of a curve makes the river double back on itself, forming a lake. We're left with an average of half-circles and an overall value of 3.14. You can see this from the air or on a map.

Knowing pi to a mere 39 places is good enough to calculate the circumference of the universe accurate to the diameter of an atom.

Simon Singh, in his 1998 book *Fermat's Enigma*, explains that the ratio varies from river to river, with the appearance of pi being "the result of a battle between order and chaos." Rivers that flow across gently sloping terrain are the ones most likely to follow the exact ratio of pi. A river cascading down steep topography moves too quickly for the pi effect to work.

We'd expect to see this on other worlds as well, except no other planet has rivers or streams of flowing water. It remains to be seen whether rivers of methane on Titan or elsewhere follow the same erosive pi-model.

Mars had flowing water millions of years ago, but no one's yet sure whether they stuck around for a long time, or else were sudden, temporary, explosive events. The fluvial channels along the martian surface are ghosts from a long-ago era, and some appear π-curvy indeed. The only other liquid water within 4 light-years of the Mississippi is not the flowing variety, but oceans under satellite ice-surfaces.

Pi is fun. You can use it for quick astroreckoning. Say you already know Jupiter's width as nearly 90,000 miles (145,000 kilometers). Mentally multiply by three and you get its circumference: about 270,000 miles (435,000 km).

Knowing Jupiter rotates in 10 hours instantly tells you its equator moves at a screaming 27,000 mph (43,500 km/h) — the planet's circumference divided by 10.

Jove's waistline thus whizzes with amazing velocity, beating our own planet's spin-speed 25 times over. No wonder its main features are horizontal streaks. Also no wonder whirling globs and chaotic eddies appear where zooming cloud belts rub against their neighbors. Suddenly a lot of things make sense. All from using pi.

In a class at a local high school, they plastered pi to 75 big digits around the room, forcing students to look at it hour after hour. In real life, its practical value requires only a few decimal places.

According to Singh, knowing pi to a mere 39 places is good enough to calculate the circumference of the universe accurate to the diameter of an atom. Anything more is clearly an annoying waste of time. So why do geeks keep going? Beats me. You'll have to, er, find one and ask.

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Professor John J. Renton says that predictions of the inevitable decrease and disappearance of worldwide oil supplies appear all too accurate. On the other hand, he notes, "Coal is to the United States what oil is to Saudi Arabia. We have more coal than anybody in the world." While other options certainly will be pursued, coal seems destined to play an important role in America's energy economy.

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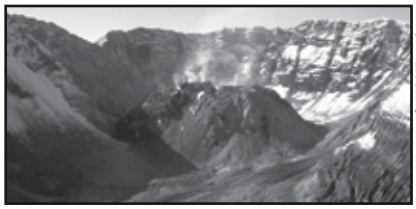

Image courtesy of USGS/Cascades Volcano Observatory.

On May 18, 1980, Mt. St. Helens exploded in the most deadly volcanic eruption in the history of the United States.

Like many geologists, Dr. Renton is plainspoken, no-nonsense, rugged, and with a tinge of romanticism. He is also an award-winning educator with 40 years of experience teaching introductory geology at West Virginia University. You will find him spontaneous, well-organized, funny, and easy to follow.

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Secret Sky
by Stephen James O'Meara

The day the Sun crawled

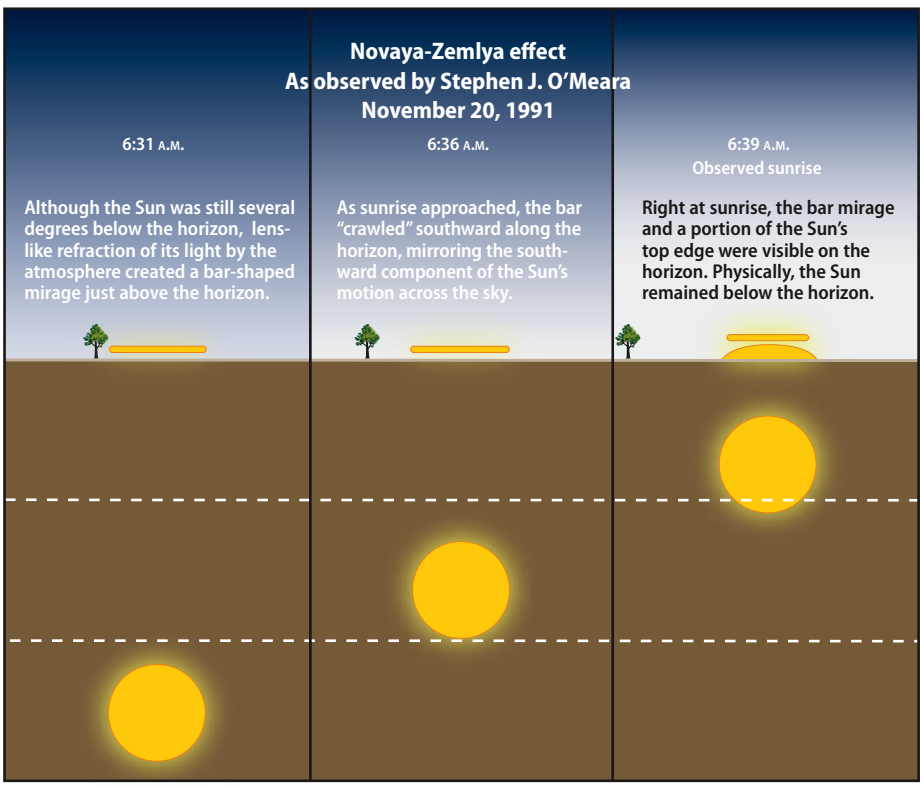
The Novaya-Zemlya effect transforms a sunset into a rare sky treat.

I'm certain that the Sun will rise tomorrow, and the next day, and the day after that. But I'm not so certain it will rise above your horizon on any given day right on schedule — especially during an "Indian Summer."

Loosely speaking, Indian Summer refers to a period of warm weather in the usually chilly central or eastern United States — about 70° Fahrenheit (21° Celsius) or warmer — after the start of fall and before the beginning of winter.

During Indian Summer, the strong flow of cool polar air that normally dips into the States during autumn weakens. This allows warm air to sweep in on southerly breezes. According to New York meteorologist Joe Rao, when these atmospheric conditions persist for several days in a row, the light winds and waning strength of the solar energy entering Earth's atmosphere often combine to produce a temperature inversion. An inversion consists of a warm, stagnant layer of air that puts an effective lid on the lower and cooler layers of the atmosphere below it.

Under certain conditions, a temperature inversion can produce a visual miracle: the apparent rise of the Sun long before its forecasted time. It's called the "Novaya-Zemlya effect," and this mysterious mirage is one of the most secret of all atmospheric phenomena. But with a little luck, you may catch sight of it this fall.


Novaya-Zemlya effect
As observed by Stephen J. O'Meara
November 20, 1991
6:31 A.M.
Although the Sun was still several degrees below the horizon, lens-like refraction of its light by the atmosphere created a bar-shaped mirage just above the horizon.
6:36 A.M.
As sunrise approached, the bar "crawled" southward along the horizon, mirroring the southward component of the Sun's motion across the sky.
6:39 A.M.
Observed sunrise
Right at sunrise, the bar mirage and a portion of the Sun's top edge were visible on the horizon. Physically, the Sun remained below the horizon.
Angle of the Sun below the horizon
–1°
–2°

The Novaya-Zemlya effect occurs when a layer of cool air trapped beneath warm air (an inversion) refracts or bends light from the rising Sun, making a bar-shaped mirage visible before sunrise. Stephen J. O'Meara observed the mirage in this illustration from Boston. *Astronomy*: Jay Smith

Mystery light

The Novaya-Zemlya effect got its name from a group of Russian islands in the Arctic Ocean, where, in January 1597, Gerrit de Veer first recorded the mirage. De Veer was a carpenter on Dutch explorer Willem Barentsz' third voyage to find a Northeast Passage to Asia.

In August 1596, Barentsz' ship became icebound, and all aboard had to overwinter on the east coast of Novaya Zemlya's large northernmost island. These pioneers weren't expecting the Sun to rise above the horizon until February 9, 1597. But de Veer recorded sighting the Sun's upper limb with two shipmates January 24 — fully two weeks early. He also vividly described the Sun's miraculous full appearance on January 27 and subsequent dates leading up to the Sun's true astronomical rising on February 9.

At first de Veer's observations were met with suspicion, because no one understood the atmospheric physics at work. Today we do.

In the June 1998 issue of *Arctic*, Siebren Y. van der Werf and his colleagues analyzed de Veer's observations. The scientists concluded de Veer's account can be explained by the bending or "ducting" of light rays parallel to Earth's surface through an inversion layer. The authors wrote, "If sunlight is captured by this duct, it may be guided along the inversion layer for as long as the duct persists. The effect bears some resemblance to the conduction of light inside a glass fibre."

When de Veer first noticed the Sun's mirage January 24, its true disk was about 5½° below the horizon. This is possible, the researchers said, if the duct extended for a length of at least 345 miles (555 kilometers). They added, "Such conditions may build up over an extended flat and cold surface." Indeed, research has shown that for every 62

During the elusive "green flash," the top of the Sun turns green for a moment during sunset or sunrise. As in the Novaya-Zemlya effect, sunlight refracting (bending) in the atmosphere causes the green flash. Stéphane Guisard/ESO

miles (100 km) that light rays travel parallel to Earth's curved surface, the Sun will appear 1° higher above the horizon.

A wake-up call

On November 20, 1991, I discovered that Earth's polar regions do not own the Novaya-Zemlya effect. I was living in a house high on a hill outside Boston, Massachusetts. It offered a commanding view of the eastern horizon, beyond which lay the vast Atlantic Ocean.

Earlier, I had begun noting the position of the Sun as it rose over familiar landmarks, as well as the time of sunrise. I wanted to know exactly where and when to look for the Sun's upper limb before it reached the horizon. This would maximize my chance of seeing the Sun's elusive green flash.

But the morning of November 20 had other plans for me. The day dawned hazy but clear, and the temperature was unseasonably warm. Suddenly, about 10 minutes before the expected time of sunrise, I saw the Sun's upper limb burning brightly on the southeastern horizon more than a degree east of where I had expected it to rise. I watched in awe as that warm orange limb crept southward along the horizon, until the Sun's full disk rose at its predicted time and location. The effect repeated itself two days later.

When the Sun rose, its appearance started off as an orange rectangle that grew evenly in horizontal layers. Soon, the Sun's rounded top mushroomed out of that growing box of light, looking like the blast cloud from an atomic explosion. The rectangular Sun is actually expected under these conditions because we see the Sun defined by the boundaries of the atmosphere within the confined duct formed by the inversion layer.

Duct hunting

If you have a clear view of the east or west horizon — the Novaya-Zemlya Effect can occur at sunset too — and would like to see the phenomenon, start recording right now the daily shift of the Sun's rising or setting position against familiar landmarks. Watch for the duct, which should appear to the naked eye (or through binoculars) as a grayish band extending up to 20 arcminutes from the horizon. The Sun will crawl along the horizon in that narrow corridor.

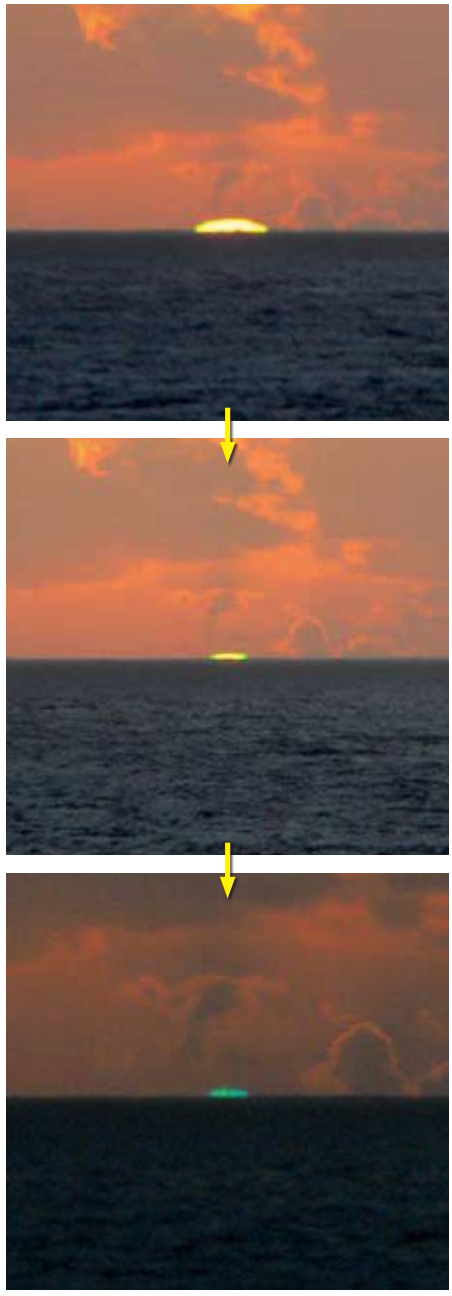
If you don't see the Novaya-Zemlya effect, don't despair. For it to occur, the Sun's rays must not only travel within an inversion layer for hundreds of miles, but the ducting layer must have just the right temperature conditions so the light follows the curvature of Earth over that great distance. Although the duct may be present, it could be too short to produce the Novaya-Zemlya effect. Also, clouds just below the inversion layer could obstruct your view of the Sun.

I saw the Sun's upper limb burning brightly on the southeastern horizon more than a degree east of where I had expected it to rise.

When to look

Finally, don't limit yourself to fall observations. Persistent temperature inversions can occur at any time of the year at various latitudes, north and south. I've also seen the Novaya-Zemlya effect from Boston in January 1992, and from California's Lick Observatory on two separate occasions, after sunset, in August 1995.

In the October 2003 *Publications of the Astronomical Society of the Pacific*, Russell Sampson of Eastern Connecticut State University and his colleagues reported observations of 244 sunrises and 135 sunsets from two locations in Edmonton, Alberta, noting that refraction effects of the Sun vary widely throughout the year. And although the greatest effects are seen during the winter months, the Novaya-Zemlya effect can occur in both warm and cold months.



The green flash is a rare and fleeting phenomenon that occurs during the first moments of sunrise — or, as seen in the sequence of images above, during sunset's last moments. Amateur astrophotographer Paul Hider captured this green flash aboard a ship sailing in the Pacific Ocean north of Pitcairn Island.

Team work On July 29, NASA and space agencies of eight other nations signed an agreement to study ways to combine their efforts to explore the Moon.

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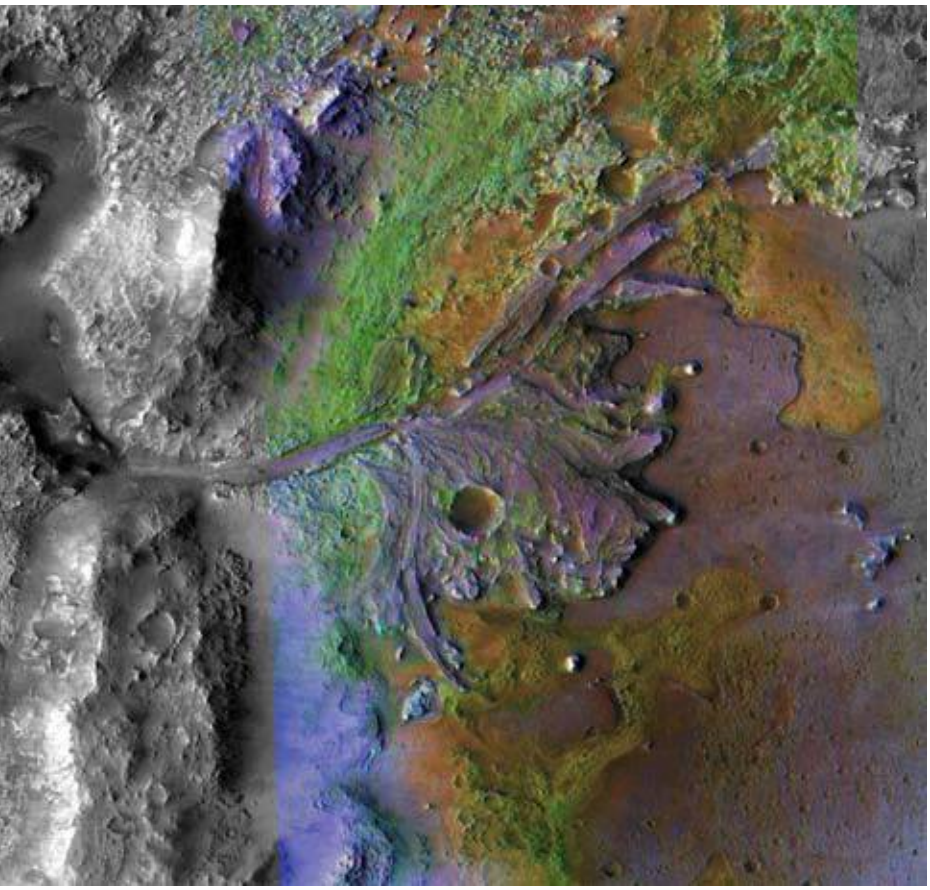

Once a watery world. In this color-enhanced image of a river delta in Jezero Crater on Mars, green indicates the presence of clay minerals transported by long-dry rivers. Clays tend to trap and preserve organic matter, making the delta a good place to look for signs of ancient life. NASA/JPL/JHUAPL/MSSS/Brown University

MRO finds new signs of a wet early Mars

Mars was once home to large lakes, rivers, and other wet environments, according to recent studies based on data from NASA's Mars Reconnaissance Orbiter (MRO). One of the reports, published July 17 in *Nature*, shows that ancient highlands of the Red Planet contain clay minerals called phyllosilicates. The mineral forms only in the presence of water and dates back to approximately 4.6 to 3.8 billion years ago.

Volcanic deposits concealed the highland regions, which cover about half of Mars, after the clays formed. But later meteorite impacts uncovered phyllosilicates at thousands of locations, making them visible to MRO's instruments today.

An additional study, published June 2 in *Nature Geosciences*, presents evidence that rivers eroded clay from the martian highlands and deposited them into a crater lake about 25 miles (40 kilometers) across. The distribution of different types of clay inside the lakebed indicates that standing water must have existed for thousands of years.

The variety of minerals in the ancient lakebed suggests different physical processes or types of wet environments created them. These would be ideal places to look for preserved traces of extinct life on Mars. — **MEGAN McCHAIN**

18 Auroral storm trigger confirmed

22 Hubble captures little spot's demise

23 Spitzer finds organic-free zone in Pinwheel Galaxy

24 Is Eta Carinae the brightest star of all?

Faraway plutoid. In this artist's portrait, the newly named plutoid Makemake circles a dim Sun in the frigid realm of the solar system beyond Neptune's orbit. IAU/M. Kornmesser (ESA/Hubble)

IAU names a new plutoid

The International Astronomical Union (IAU) in Paris has officially named the third plutoid in our solar system Makemake, after the Polynesian creator of humanity and the god of fertility. Formerly known as 2005 F_{9}, Makemake (pronounced MAH-keh MAH-keh) joins two other dwarf planets — Pluto and Eris — in the IAU's new plutoid category.

Plutoids are Pluto-like dwarf planets that lie beyond Neptune and have not completely swept their orbits clear of smaller debris. Astronomers from Caltech discovered Makemake in 2005. — **M. M.**

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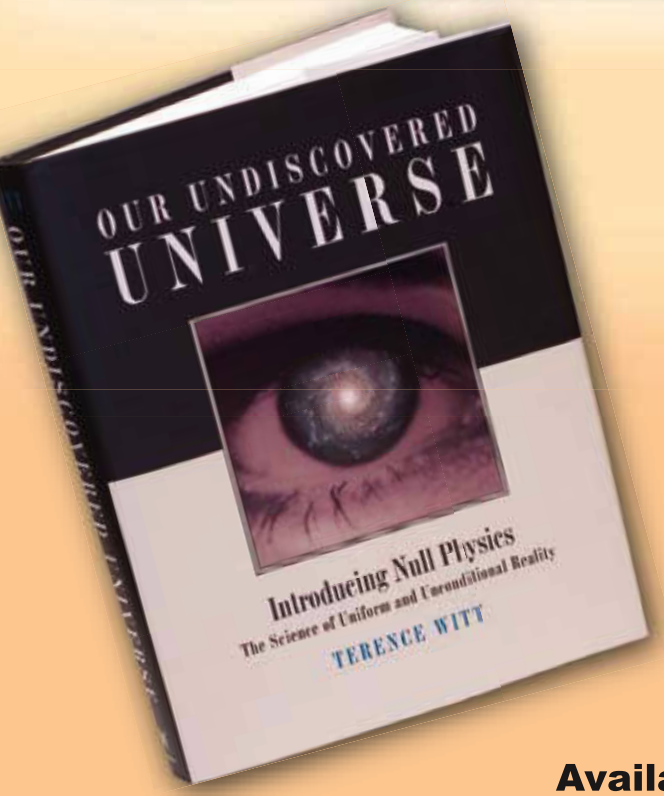

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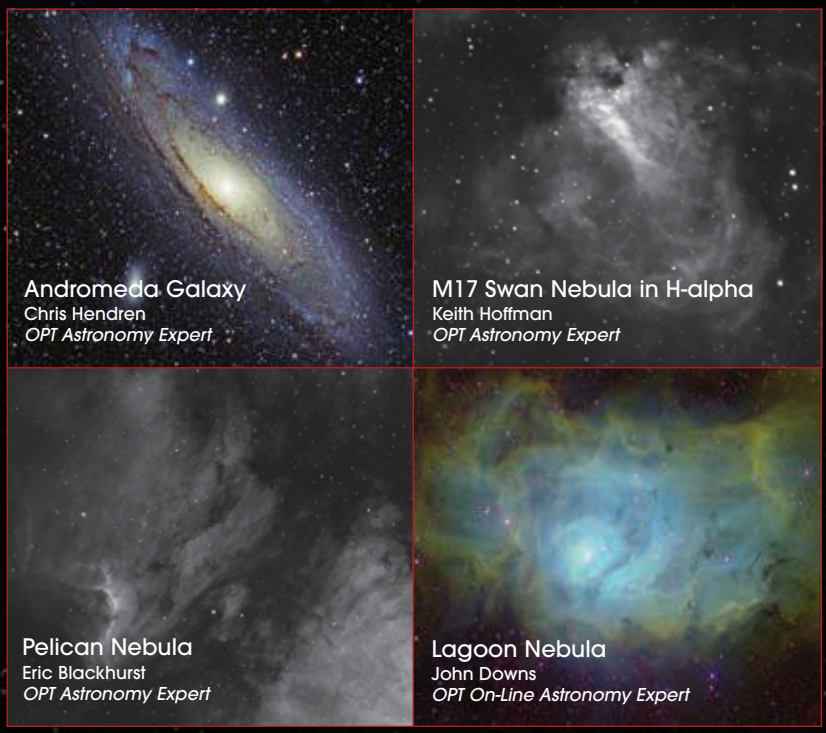

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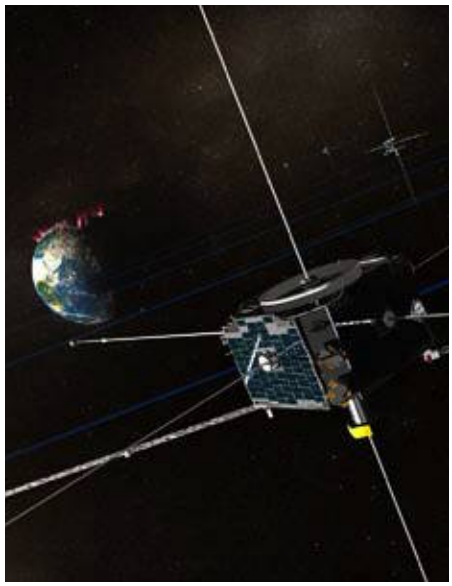


Substorm watchers. Five identical satellites observe aurorae from space as part of NASA's Time History of Events and Macroscale Interactions during Substorms (THEMIS) mission. NASA

Auroral storm trigger confirmed

NASA's THEMIS mission has revealed what sets off sudden flare-ups of aurorae around Earth's poles, scientists reported August 14 in *Science*. The key mechanism is a sudden whiplash of Earth's magnetic field known as magnetic reconnection.

"We discovered what makes the northern lights dance," said Vassilis Angelopoulos of the University of California, Los Angeles. Angelopoulos is the lead scientist for the Time History of Events and Macroscale Interactions during Substorms (THEMIS) mission.

In February 2007, NASA launched the mini-flotilla of five identical satellites. They orbit at different locations in Earth's magnetic field. Scientists used the satellites in concert with a network of 20 ground-based auroral observatories to monitor the beginning of auroral flare-ups, known as substorms.

Observations February 26, 2008, confirmed that substorms trace to a process called magnetic reconnection. As the flow of charged particles from the Sun compresses Earth's magnetic field, it suddenly snaps to a new shape, like a rubber band that's been stretched and suddenly released. The recoil flings charged particles toward Earth's poles and triggers substorms, in which the brightness and extent of the aurora surges dramatically. — **DANIEL PENDICK**

25 years ago in *Astronomy*

November 1983

In the November 1983 issue of *Astronomy*, Andrew Maslowski discussed what Earth is telling us about other celestial bodies in "Geology from space." Maslowski focused on a geologic theory called uniformitarianism.

Developed at the end of the 18th century by Scottish farmer James Hutton, uniformitarianism simply states that the same geological processes happening today occurred in the past. Uniformitarianism made studying the present Earth the key to understanding its history.

The study of terrestrial geological processes has allowed astronomers to unlock the mysteries of worlds other than our own. "In essence," Maslowski wrote, "the modern union of geology and astronomy — planetology — proceeds to weave a single coherent story out of dozens of individual examples that make up the Sun's retinue of solid bodies."

10 years ago in *Astronomy*

The November 1998 issue of *Astronomy* traveled 6,500 light-years away into the Crab Nebula. Robert Zimmerman's exploration of the Crab, "Into the Maelstrom," explained the life of this colossal and famous supernova remnant. Exploding almost 1,000 years ago, the Crab is one of the closest, brightest, and youngest nebulae in the sky.

Chinese astronomers first spotted the exploding star's beaming light in the night sky in 1054. Later, in the 18th century, Charles Messier observed the supernova's expanding remnant. Seeing the Crab inspired him to create his famous list of observable deep-sky objects. Swelling 932 miles (1,500 kilometers) a second, the Crab Nebula is expected to continue glowing for at least another million years. — **M. M.**

November 1998

BRIEFCASE

Canada to launch new asteroid hunter

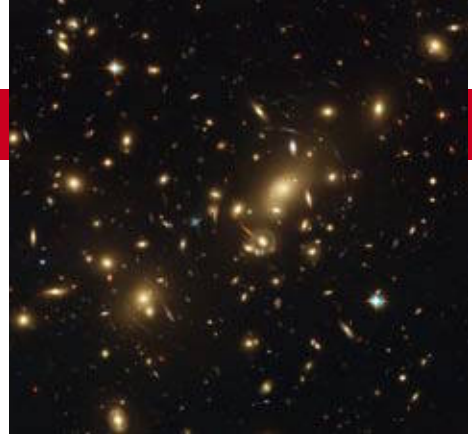
Canada is building the first spacecraft designed to find and track both asteroids and satellites. The Near Earth Object Surveillance Satellite (NEOSSat) will monitor potential Earth-colliding asteroids and Earth-orbiting satellites. The $12 million spacecraft will weigh just 143 pounds (65 kg) and occupy the volume of a large suitcase. — M. M.

Take the Soyuz tour

The Russian space agency and an unnamed private investor have signed an agreement to build a special Soyuz spacecraft to loft pairs of paying tourists into space by 2011. The investor could be Space Adventures, a private American company that signed a deal in June with Russia for a commercial flight to the International Space Station. Space Adventures has already sent five tourists into space at ticket prices up to $25 million each. — M. M.

Through alien eyes

NASA's Deep Impact spacecraft has created a video of the Moon passing in front of (transiting) Earth, as seen from the spacecraft's point of view 31 million miles (50 million kilometers) distant. Scientists will use the video to develop better methods to study alien exoplanets transiting their host stars. Deep Impact encountered Comet Tempel 1 July 4, 2005, but is now on an extended mission to rendezvous with Comet Hartley 2 November 4, 2010. — D. P.



Through the lens brightly. The thin arcs scattered in this galaxy cluster, Abell 2218, represent light from more distant objects "lensed" by the cluster's gravity. NASA/ESA/Johan Richard (Caltech)

Hubble finds most distant galaxies yet

Astronomers used galaxy clusters like telescope lenses to magnify 10 galaxies as they existed 13 billion years back in cosmic time, Hubble scientists announced July 24. Some of the objects are dimmer than the faintest galaxies seen in the legendary Hubble Ultra Deep Field — the space telescope's most distant view of the universe to date.

The observations, obtained with the Hubble Space Telescope, are just the latest in a mounting list of achievements possible thanks to the gravitational lensing effect. The massive gravity of a galaxy cluster can bend light passing around it, like a refracting telescope's primary lens brings an image to a focus. Bending of light by the clusters allowed Hubble to see brighter views of the distant galaxies lying behind the gravitational lens. — **D. P.**

Gary Palmer is an X-treme astronomer who likes to get up close and personal to our closest star. You can too at the Arizona Solar Conference Nov. 7, 8 and 9, 2008. Catch the excitement of viewing the sun through LUNT Solar Telescopes.
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The $549 **Astro-Tech AT80ED** is just such a refractor.

For $549 you get fully-multicoated 80mm f/7 ED doublet optics; a rotating dual-speed 2" Crayford focuser, with 2" and 1.25" compression ring eyepiece holders; and a locking transport/storage hard case. The AT80ED has dual hinged split tube rings plus a separate Vixen-style dovetail for mounting the scope on virtually any altazimuth or German equatorial mount (not just a simple clamshell or mounting foot as with competitive scopes).

For only $150 additional you can even upgrade to a factory-installed *Feather Touch* dual-speed microfocuser.

The **Astro-Tech AT80ED**. $549. Where else can you get a product for so little money that's a great performer today and could easily continue to perform at its best for decades?

A 2007 Hot Product, still hot in 2008!

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This **Astro-Tech 1.25" star diagonal**, like all Astro-Tech diagonals, has 46-layer 99% reflective *dielectric* coatings on its premium 1/10th wave BK7 optical glass substrate. 2" Astro-Tech BK7 dielectrics start at $119.95, *quartz* at $189.95.

The AT80EDT ED triplet got a 4-star review.

The review said this 80mm f/7 Astro-Tech ED triplet had "essentially textbook-perfect diffraction images . . . I counted scores of star clusters during a casual sweep from Auriga to Cassiopeia . . . Stars appeared sharp and round . . . Daytime photographs are contrasty and free of color fringes, even with challenging subjects like tree branches against a bright, blue sky . . . an ideal travel scope, and one that I'd welcome for observing and photography at any solar eclipse."

Astro-Tech AT80EDT
80mm f/7
ED triplet
$699

For $699 you get ED triplet apo optics with a collimatable lens cell for peak images; a *carbon fiber* optical tube; a dual-speed focuser; 2" and 1.25" compression ring eyepiece holders; hard case; and dual split rings for mounting the AT80EDT on virtually any German equatorial mount or dovetail.

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On your mark, get set. The launch of NASA's Lunar Reconnaissance Orbiter in 2009 will signal the United States' return to the Moon for human exploration and basic science. NASA

The U.S. return to the Moon begins

NASA's intention to renew human exploration of the Moon is about to transition from the talk stage to real action. Its Lunar Reconnaissance Orbiter (LRO) — the first American robotic Moon mission since 1994 and only the second such NASA mission in 40 years — is scheduled for launch in early 2009.

The universe of lunar exploration has changed since the bipolar "Moon Race" of the 1960s. LRO will join other lunar orbiters from China and Japan (and possibly India), following the highly successful European SMART-1 probe that has already completed its mission. So just getting to lunar orbit is no longer sufficient to bestow special status. A new probe has to perform something special. In LRO's case, it will be two specials.

The new NASA probe carries instruments with the goal of identifying the most interesting and feasible locations for human landings. With that intention, it will be expanding the search for water ice in shadowed polar craters.

The ice, if it exists and is accessible to astronauts, could be a source of water and fuel for future astronauts. Moreover, because the ice deposits probably exist in multiple layers separated by episodic geological deposits, they may represent the pages in a history book of the Moon and the Sun over the past billion years or so.

LRO's two-stage mission plan reflects the two different applications of the ice deposits: support for human exploration and scientific research. For the first year, the probe is the responsibility of the mission development team focused on human exploration. But then the planetary science team will take over and run LRO's instruments according to different priorities and targets.

A similar shift in emphasis will occur with LRO's imaging systems. From its low, 30-mile (50 kilometers) polar orbit, the probe will map candidate landing sites, including their topography, geochemistry, and roughness. LRO's cameras can see features as small as 3.3 feet (1 meter), the sharpest eyesight of any lunar orbiter ever and as good as commercial observation satellites in Earth orbit.

Once NASA shifts LRO to pure science, the craft will concentrate on highly precise mapping of the Moon's shape. Scientists hope this data will reveal more about the Moon's internal structure and history.

Piggybacking on LRO's launch is the Lunar CRater Observation and Sensing Satellite (LCROSS). In 2009, its spent second-stage booster rocket will slam into a lunar crater. LCROSS will then search the debris plume for traces of water.

After mission end, LRO will run out of orbital adjustment gas and eventually crash-land on the Moon's surface — freeing up some extra orbital space for the parade of follow-on spacecraft now in development. It's about time the U.S. return to the Moon got underway. — **JAMES OBERG**

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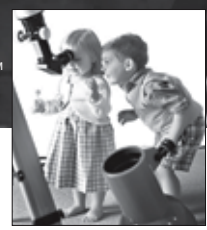

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Astro-Tech Ritchey-Chrétiens start at only $1295. *That price is NOT a misprint.*

AT8RC Astro-Tech 8" R-C

Up until now, the coma-free optics of *true* Ritchey-Chrétien optical systems came only in custom-made large apertures at prices that *started* well north of $10,000. That put true R-C astrographs out of the reach of most astrophotographers.

But Astro-Tech knew that state-of-the-art computerized mirror grinding, CNC machining, and modern production techniques could produce reasonably-priced R-C astrographs with the optical performance you once had to pay a fortune to get.

That's why Astro-Tech is proud to introduce the Astro-Tech RC Series – top-quality *true Ritchey-Chrétien* astrographs at prices you don't have to be a millionaire to own.

Astro-Tech AT6RC: A 6" f/9 ideal for coma-free imaging with webcams, Deep Sky Imager-type cameras, and ST-7/8/9-class CCDs. Aluminum tube, BK-7 mirrors, 1/12th wave or better optics, Crayford focuser, Vixen-style dovetail, dust cover **$1295**

Astro-Tech AT8RC: An 8" f/9 for imaging with 35mm large format (STL-type) CCD cameras and long imaging equipment trains. A light weight/high strength *carbon fiber* tube, quartz mirrors, *dielectric* mirror coatings, 1/12th wave or better optics, genuine *Feather Touch* focuser, hard case, Losmandy-style dovetail, dust covers **$2995**

Astro-Tech AT10RC: A 10" f/9 with the same features as the AT8RC, but with a larger aperture and two cooling fans. Compare at $14,000 ..... **approximately $4995**

Also in development are 12" and 16" Astro-Tech Ritchey-Chrétiens. Prices have yet to be finalized, but they will be sensibly and affordably priced in line with the prices of the smaller Astro-Tech R-Cs above. Their prices will make you wonder why other RC manufacturers charge as much as $17,000 for a 12.5" R-C and $34,000 for a 16".

Three TMB triplet apos in stock starting at $995.

$3999 TMB-130 triplet apo

The 130mm f/7 **TMB-130** apochromatic ED triplet, left, is a *Hot Product for 2007.* Unlike other ultra-premium apo refractors with multiyear waiting lists, this big ED triplet apo is available now.

$1999 TMB-92 triplet apo

The ultra-compact (only 13.25" long!) 92mm f/5.5 **TMB-92** triplet apo, right, capably fills the void left by the discontinued 90mm Astro-Physics Stowaway (a legendary refractor that sells for up to $6000 on the used market, when you can find it). But the new TMB-92 is only $1999, not $6000 – *and it's available now.*

The above scopes have collimatable lens cells, FPL-53 ED glass, a genuine *Feather Touch* dual-speed rotating rack and pinion focuser, compression ring eyepiece holders, carrying case, and more.

$995 TMB-80 triplet apo

The **TMB-80**, right, is an 80mm f/6.3 triplet apo with FPL-53 glass for only $995! It's the first time a genuine TMB apo refractor has been available at such an attractive price. A true TMB for under $1000? Wow!

The Astro-Tech Voyager – "a really sweet grab-and-go."

A recent magazine review said that the $299 **Astro-Tech Voyager** altazimuth mount was "unusually stable for its size and weight" and was packed with "lots of first-class engineering" that made it "a really sweet grab-and-go setup that's ideal for viewing day or night."

The Voyager has a 20 pound payload capacity, automatic clutch worm drive manual slow motion controls, adjustable height aluminum tripod, Vixen-style dovetail, and a very affordable price. The Voyager is clearly today's best value in serious altazimuth mounts.

$299 Astro-Tech Voyager with optional Astro-Tech 4" AT102ED

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Celestron 8" CPC800 **$1999**

It's easy to find your way around the sky with a **Celestron CPC** go-to telescope. Just point it at any three bright lights in the sky (3 stars, or 2 stars and a planet or the Moon), and your CPC finds over 45,000 deep space and solar system objects for you at the touch of a button.

You don't have to enter your time or location or memorize a star chart to use a CPC. Its built-in GPS and a few anonymous lights in the sky are all you need.

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TeleVue 100° field 8mm Ethos. $585 and worth it.

Few eyepieces have received as many rave reviews as the $620 100° field 13mm TeleVue Ethos. It proved that an eyepiece costing more than many complete telescopes was indeed worth the money. Now the 13mm is joined by the 100° field **TeleVue 8mm Ethos**. Let the rave reviews begin all over again.

The 8mm Ethos is one of 41 superb TeleVue eyepieces starting at only $85.

A Meade LX200-ACF has "Ritchey-Chrétien-like" optics at a fraction the cost of a true R-C.

Meade 8" LX200-ACF **$2899**

Sky & Telescope said Meade's original Advanced Coma-Free f/8 catadioptric go-to scope "does indeed perform like a Ritchey-Chrétien." And *Astronomy* said it "delivers Ritchey-Chrétien-like performance at a fraction the cost."

Meade LX200-ACF go-to catadioptric scopes have f/10 versions of those same highly-reviewed coma-free optics, but at prices that make "Ritchey-Chrétien-like" optical performance affordable.

True Ritchey-Chrétien reflectors are usually available only as an optical tube. Mounts are extra. Not so with a Meade LX200-ACF. Each comes with a full GPS-based computerized go-to mount, tripod, finderscope, eyepiece, and much more – but at only a fraction the cost of a comparably-sized R-C optical tube only.

A Meade LX200-ACF with "Ritchey-Chrétien-like" Advanced Coma-Free optics, state-of-the-art UHTC multicoatings, *and* a full GPS go-to mount and tripod, can be yours for only $2899!

Here are the *freight-paid* prices for the Meade LX200-ACF catadioptric scopes:

8" LX200-ACF, with UHTC and tripod **$2899**
10" LX200-ACF, with UHTC and tripod **3999**
12" LX200-ACF, with UHTC and tripod **4999**
14" LX200-ACF, with UHTC and tripod **6999**
16" LX200-ACF, with UHTC and tripod .. **14,999**

The Celestron Sky Scout *with GPS,* only $299.

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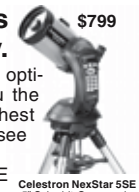
The award-winning **Celestron SkyScout** is a *GPS-based* non-magnifying hand-held personal planetarium. It locates and identifies for you more than 50,000 celestial objects, including every one visible to your unaided eye. Earbuds tell you their stories, or you can read the scrolling 5-line text and graphics display. Optional accessories expand its capabilities and let you use it to control Celestron go-to scopes.

The Celestron NexStar SE go-to scopes are four of the best values in astronomy.



$799 Celestron NexStar 5SE 5" Schmidt-Cassegrain

Many of the advanced features in the fully-equipped **Celestron NexStar SE** go-to telescopes were unavailable at *any* price only a few years ago.

For example, their *SkyAlign* go-to computers make astronomy easy as 1-2-3. Just point your scope at three bright stars (or two stars and the Moon or a planet) to line it up on the sky so it can find 40,000 celestial objects for you. You don't even have to know which stars they are!

And their Starbright XLT optical multicoatings give you the brightest images and highest contrast ever, so you can see more, and see it better!

Is a Celestron NexStar SE a great value? *Absolutely!*

NexStar 4 SE, 4" Maksutov **$599**
NexStar 5 SE, 5" Schmidt **799**
NexStar 6 SE, 6" Schmidt **999**
NexStar 8 SE, 8" Schmidt **1399**

Great Astro-Tech eyepiece values from $39.95 to $99.95.

Series 6 1.25" 20mm

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At only $39.95 each, **Astro-Tech Series 6** fully multicoated wide field 1.25" eyepieces, left, are great for everyday use and inexpensive enough to buy two at a time for a binoviewer. The 8mm and 12mm have a 60° field, while the 17mm and 20mm have 65°.

The **Astro-Tech Titan** 1.25" and 2" eyepieces have wide 70° fields, twist-up rubber eyecups, good eye relief, and all are less than $99.95.

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Titan – 2", 70° field, 26mm **79.95**
Titan – 2", 70° field, 32mm **89.95**
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$749 Astro-Tech AT80LE 80mm f/6 ED doublet

Only Astro-Tech gives you so much performance and so many features for so little money.

The apo doublet optical system of the 80mm f/6 **Astro-Tech AT80LE** uses genuine Ohara glass with a costly FPL-53 ED element, not merely FPL-51 as with competitive scopes. Unlike other scopes, the AT80LE lens is collimatable for peak images.

Its carbon fiber body and retractable dew shield combine high strength and low weight. You get a dual-speed Crayford focuser, compression ring eyepiece holders, dual hinged tube rings, a hard case, and a *2-year* warranty. It's a steal at $749.

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Rosetta's stone On September 5, the European Rosetta spacecraft made its rendezvous with asteroid 2867 Steins, passing within 500 miles (800 km) of the space rock.

Planetary road kill. The Hubble Space Telescope caught the encounter between the Little Red Spot and the centuries-old Great Red Spot. NASA/ESA/A. Simon-Miller (GSFC)/N. Chanover (NMSU)/G. Orton (JPL)

Hubble captures little spot's demise

A new red spot that appeared on Jupiter in May 2008 was mangled July 8 in a collision with the Great Red Spot, a long-lived rotating storm on Jupiter. The two storms were on a collision course because they plied similar latitudes of Jupiter's cloud bands.

A sequence of Hubble Space Telescope images showed the tiny spot's fate. A different storm, Red Spot Jr., passed by safely south of the Great Red Spot June 28. About a week later, the little spot passed into the Great Red Spot's counterclockwise rotation. On July 8, it looked like mangled road kill in a Hubble snapshot. — **D. P.**

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Full blast. The four-plumed Orion jettison engine undergoes an upside down test firing as part of the development of an emergency escape system for the Ares I rocket. Aerojet

Astronaut rescue rocket revs up

On July 17, NASA conducted its first full-scale test firing of the Orion jettison engine at the Sacramento, California, test facility of the aerospace contractor Aerojet. Orion, currently under development, consists of a crew capsule, service module, and rockets to allow astronauts to travel to the International Space Station, the Moon, and other destinations.

At launch, Orion rides atop the Ares I rocket. In the event of an aborted launch, a four-nozzle jettison rocket will carry the crew capsule to safety. The Aerojet test was one of a series to prepare the rocket hardware for the first full-scale test of Orion's launch abort system later this year. — **M. M.**

Organic-free zone. **In this Spitzer Space Telescope image, the reddish color of M101's periphery indicates a virtual lack of organic molecules in the galaxy's interstellar spaces.**
NASA/JPL-Caltech/Potsdam University

Spitzer finds organic-free zone in Pinwheel Galaxy

The galaxy M101 is famous for its abundance of bright spiral arms. But new Spitzer Space Telescope images show a zone within the Pinwheel Galaxy surprisingly lacking in organic molecules called polycyclic aromatic hydrocarbons (PAHs), astronomers reported July 20 in *The Astrophysical Journal*.

PAHs are carbon-based molecules commonly seen in star-forming regions. On Earth, PAHs turn up in barbecue pits, automobile exhaust pipes, and other places where combustion reactions take place.

In M101, the PAH concentration decreases with distance from the center, but then suddenly drops off at the galaxy's edge. They cannot be detected at all at the outer edge.

PAHs may be raw materials for life in the cosmos, so the "no organics" zone at M101's periphery might imply hostile conditions. "If you were going to look for life in Messier 101, you would not want to look at its edges," said study leader Karl D. Gordon of the Space Telescope Science Institute in Baltimore, Maryland. "The organics can't survive in these regions, most likely because of high amounts of harsh radiation." — **D. P.**

Watching a stellar tantrum

In 2007, astronomers at the European Southern Observatory (ESO) in Chile watched as a star experienced a violent outburst and blew shells of gas around itself, astronomers reported July 24 in *Astronomy and Astrophysics*. The star, V1280 Scorpii, was in the midst of a sudden brightening, or nova phase, due to explosions on its surface.

Japanese amateur astronomers discovered V1280 Scorpii February 4, 2007. It reached its maximum brightness February 17, becoming one of the brightest novae of the past 35 years. At its brightest, the nova was easily visible with the unaided eye.

Astronomers used ESO's Very Large Telescope Interferometer to observe the nova in extraordinary detail. Eleven days after the nova's brightness peaked, the ESO observers saw the formation of a dust shell around the star. The dust persisted more than 200 days, making the star 10,000 times dimmer. ESO astronomers continued to observe the event for 5 months. — **D. P.**

QUICK TAKES

MOONBOT FINALISTS
The European Space Agency has chosen eight university teams to compete in its Lunar Robotics Challenge to design a vehicle to explore the Moon.

CLOSER LOOK
The Venus Express probe changed to a lower orbit August 4 to make new types of observations possible.

LUNAR GPS
NASA has awarded $1.2 million for the development of a GPS-like system for use by astronauts when Americans return to the lunar surface.

BRIGHT TRASH
A refrigerator-sized ammonia container tossed overboard by space station astronauts last year is now visible to earthbound observers.

EDGY IMAGING
In July, scientists said NASA's STEREO spacecraft detected neutral atoms from the edge of our solar system, making it possible to map the edge of interstellar space in a new way.

GROWING SPACE
NASA signed an agreement July 23 with the Department of Agriculture to conduct plant research on the International Space Station, using it like a national laboratory.

MURPHY 3, SpaceX 0
On August 3, the commercial spaceflight company SpaceX lost its third Falcon 1 rocket in a row. The rocket's first and second stages failed to separate about 2 minutes and 20 seconds after liftoff.

COROT'S 50K
In July, the European extrasolar planet hunting COROT satellite observed its 50,000th star in a search for planets beyond our solar system.

SPACE IMAGE GOLDMINE
On July 24, NASA and a nonprofit library, the Internet Archive, launched www.nasaimages.org, a searchable repository of NASA photographs, historic film, and video.

JUST SWINGING BY
In July and August, the European Space Agency's Mars Express swung within 62 miles (100 km) of the martian moon Phobos during a series of close flybys.

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Chinese data leak In August, China released more than 700 hours of Chang'e-1 lunar orbiter data to the European Space Agency and authorized domestic users.

Deep gaze. This composite of three Spitzer images reveals the brilliant Peony Nebula star deeply obscured by dust near the Milky Way's center. NASA/JPL-Caltech/Potsdam University

Is Eta Carinae the brightest star of all?

The Spitzer Space Telescope identified a potential challenger to the title of brightest star in the Milky Way Galaxy, scientists announced in a report slated for publication in *Astronomy and Astrophysics*. It's called the Peony Nebula star, and it shines with the brilliance of 3.2 million Suns.

The reigning champ remains Eta Carinae, glowing with the light of an estimated 4.7 million Suns. But because such estimates of stellar wattage remain uncertain, the Peony Nebula star could ultimately best Eta Carinae.

The Peony Nebula star lies deep in the Milky Way's dusty central hub. Astronomers observed it using the Spitzer Space Telescope, whose infrared detectors can peer through dust that obscures other wavelengths. Combining Spitzer's view with observations from the European Southern Observatory's New Technology Telescope in Chile enabled scientists to make a new estimate of the Peony Nebula star's luminosity, or total light output.

Both Eta Carinae and the Peony Nebula star are massive stars, which typically end in a spectacular supernova blast. Amateur stargazers wanting a look for themselves will need patience, though. The Peony Nebula star could go off any time from now to 10 million years from now. — **D. P.**

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See page 79 for more details and official rules.

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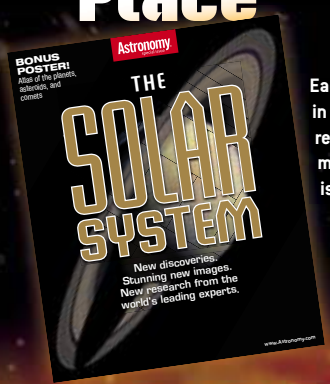
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Are SUPER-SIZED EARTHS the new frontier?

Astronomers are starting to find exoplanets not much bigger than Earth. Some scientists think these worlds could be more hospitable to life than our planet. **by Ray Jayawardhana**

It hasn't been long — a mere 13 years — since astronomers discovered the first planet orbiting a star other than the Sun. Yet, announcements of planet finds already have become routine. The count of planets orbiting normal stars recently passed 300. The vast majority of these worlds are gaseous behemoths similar to Jupiter and Saturn. Still, researchers have uncovered several akin to Neptune.

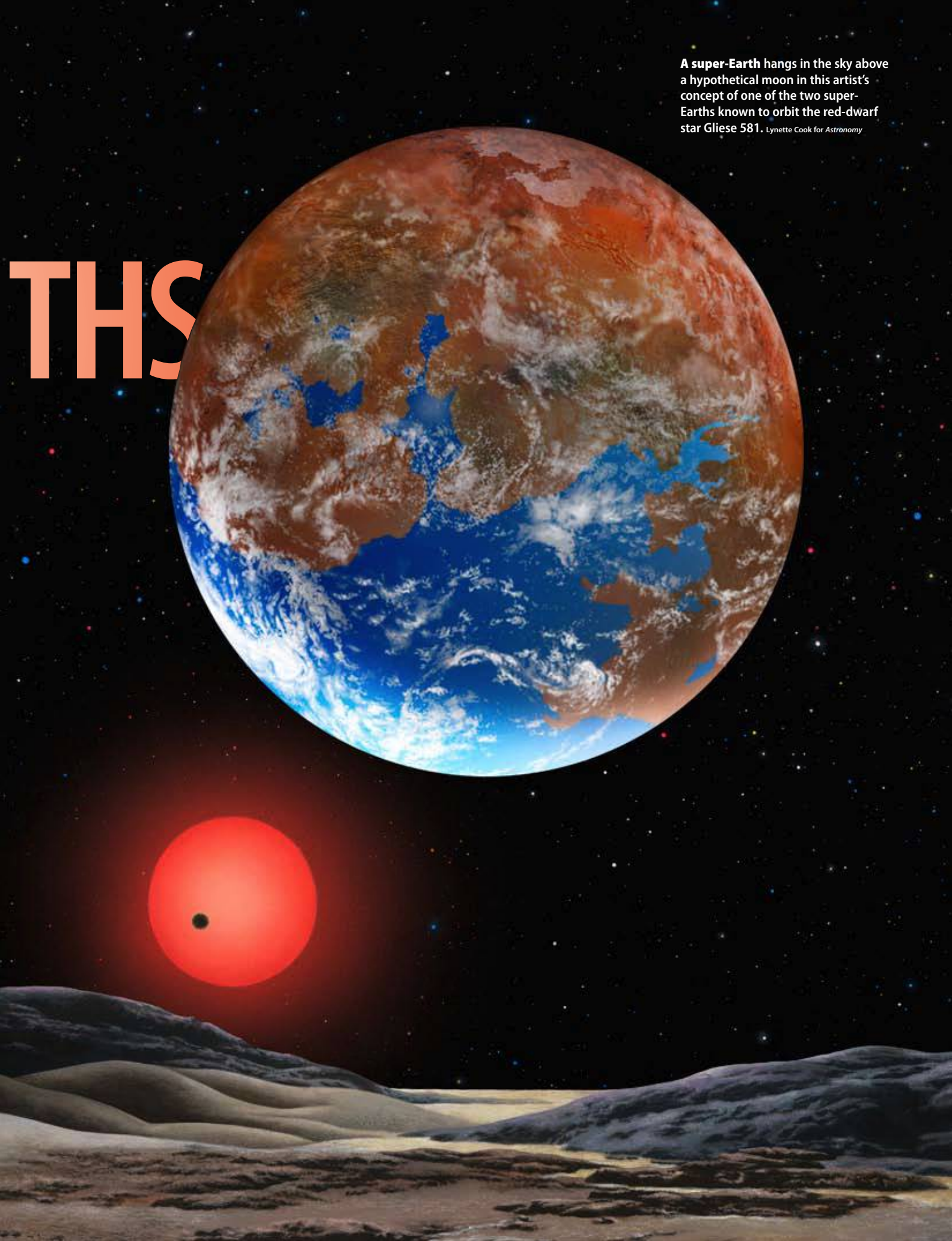
Although discovering an Earth twin remains slightly beyond our reach, the newest denizens in the planetary zoo have only a few times more mass than our planet. Called "super-Earths," these exotic worlds don't exist in our solar system. But astronomers think that if one orbits at the right distance from its parent star, a super-Earth could be even more hospitable to life than Earth itself.

Heftier planets continue to be easiest to find. Such a world tugs harder on its star, producing a larger velocity shift in its spectral lines. A Jupiter analog, for example, makes its star twirl at about 28 mph (45 km/h). That's well within the detection limits of current spectrographs.

Bigger planets also cause larger dips in a star's brightness when they transit. A Jupiter-sized planet passing in front of a Sun-like star covers about 1/100 of the star's face. This results in the star dimming by 1 percent for a few hours, which astronomers can measure from the ground.

As Doppler measurements have become more precise, astronomers now can detect velocity shifts as small as 2.2 mph (3.6 km/h). That's good enough to reveal the presence of planets only a few times Earth's mass. Their minuscule dips in brightness during transits, however, remain tough to detect from the ground, unless the planet orbits a small star.

Contributing editor **Ray Jayawardhana** *holds the Canada Research Chair in Observational Astrophysics at the University of Toronto. His research focuses on the origins of planets, brown dwarfs, and stars.*



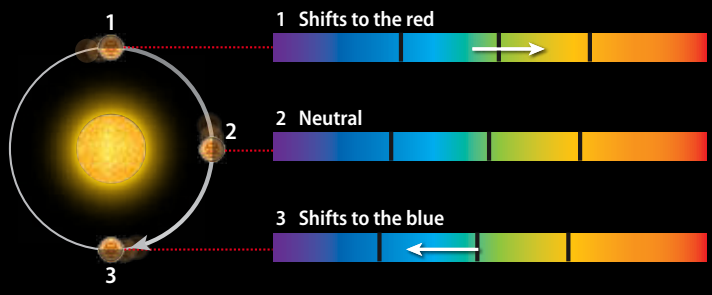
A super-Earth hangs in the sky above a hypothetical moon in this artist's concept of one of the two super-Earths known to orbit the red-dwarf star Gliese 581. Lynette Cook for *Astronomy*

Detecting new worlds

Astronomers search for exoplanets through their effects on a parent star's light. The three techniques below have revealed all known super-Earths. *Astronomy:* Roen Kelly

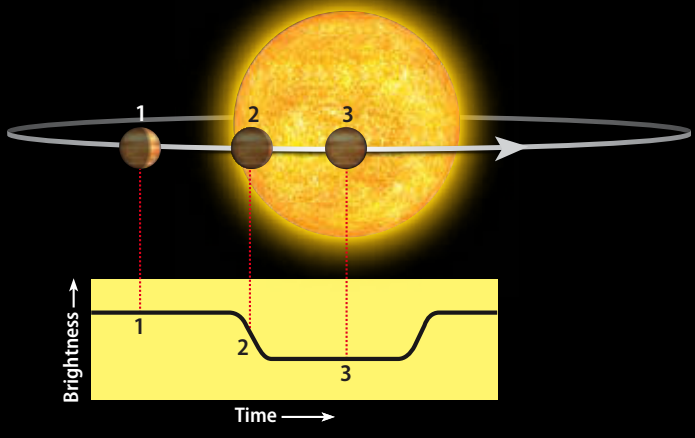
Radial-velocity method

An orbiting planet tugs on its star, inducing a wobble in the star's motion. The star's spectral lines shift to the blue as the star approaches and to the red as it recedes.



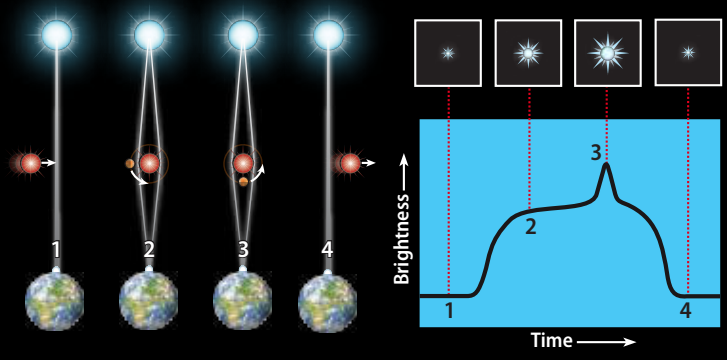
Transit method

If a planet's orbit lies along our line of sight, the planet will pass in front of its star once each orbit. The planet then causes a dip in the star's brightness.



Microlensing method

If a star passes in front of a more distant one, the closer object's gravity acts like a lens and causes the distant star to brighten. A planet orbiting the nearer object will add a slight blip to the otherwise smooth light curve.



The first super-Earth

Using the Doppler technique, researchers have found several super-Earths. The first one, announced in 2005, holds 7.5 Earth-masses and orbits the red-dwarf star Gliese 876. (For comparison, Neptune contains 17 Earth-masses.) Earlier observations had shown two gas giants circling this star. Jack Lissauer and Eugenio Rivera at NASA's Ames Research Center at Moffett Field, California, deciphered the presence of the third, less massive planet only after accounting for the resonant interactions between the two large ones.

The two astronomers mined years of data from the California-Carnegie planet search team, led by Geoffrey Marcy and Paul Butler, to unravel the super-Earth in a 2-day orbit. The planet lies so close to Gliese 876 that it probably is tidally locked, rotating on its own axis in the same time it takes to revolve around the star. So, the same hemisphere always points to Gliese 876, just as one side of the Moon always faces Earth.

The planet's permanent dayside should be oven-hot, at somewhere between 400° and 750° Fahrenheit (200° and 400° Celsius). The nightside temperature would depend on how efficiently the planet's atmosphere (if any) distributes the heat through global wind streams.

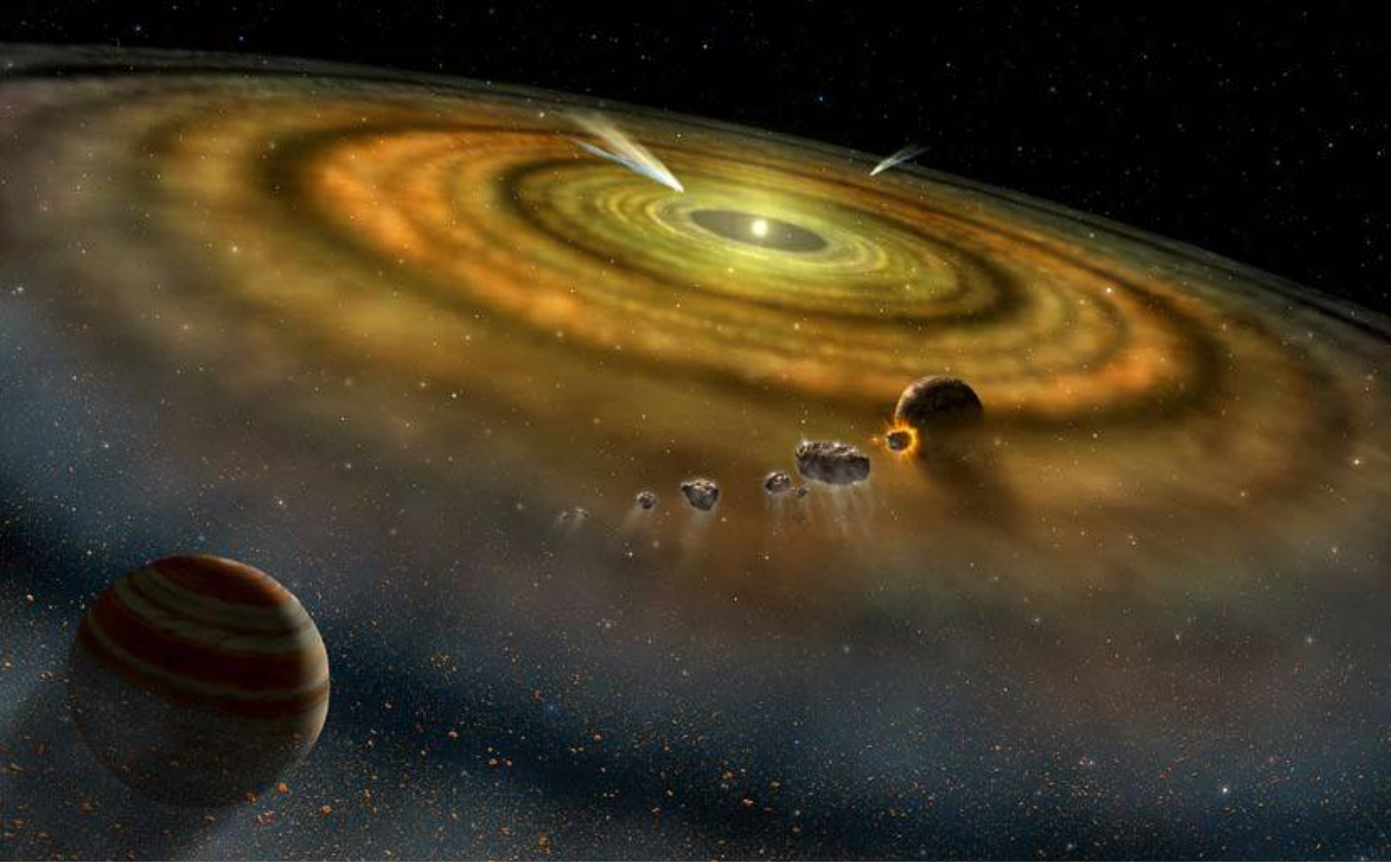
Last year, Stephane Udry of the Geneva Observatory and his colleagues, including team leader Michel Mayor, discovered two super-Earths around Gliese 581. (This red-dwarf star also harbors a hot Neptune.) One of the newly discovered planets has a minimum mass 5 times that of Earth and lies closer to the star than Mercury does to our Sun. This world completes an orbit every 13 days.

The other planet, which weighs at least 8 Earth-masses, orbits at a quarter of the Sun-Earth distance and takes 83 days to go around. The inner planet is probably too hot for liquid water to exist on its surface and the outer one a bit too cold, although their temperatures would depend on the nature of any atmosphere.

The Geneva team used a high-precision spectrograph on the 3.6-meter telescope at the European Southern Observatory at La Silla, Chile, to detect the subtle wobbles of the parent star caused by these super-Earths. The researchers now are targeting 100 other low-mass stars like Gliese 581, as well as hundreds of Sun-like stars, with the same instrument in their quest for terrestrial and super-terrestrial worlds.

The most recent find

This June, the team announced its latest haul: four new super-Earths, all having masses between 3 and 9 times that of Earth, but with orbital periods ranging from a few to 20 days. Three of them orbit the star HD 40307, which has slightly less mass than the Sun. The fourth circles HD 181433 along with a Jupiter-like planet in a 3-year orbit. "Clearly these planets are



Planets start to accrete in the dusty disk surrounding the young star Beta Pictoris. This artist's concept shows the gradual build-up of smaller chunks into larger ones. If a planet's rocky core remains smaller than 10 Earth-masses, it should form a super-Earth and not a gas giant. NASA/FUSE/Lynette Cook

only the tip of the iceberg," says Mayor, who claims that a third of all Sun-like stars in their sample betray hints of super-Earths or Neptune-mass planets in orbits shorter than 50 days.

The coolest and most distant super-Earth known was discovered through gravitational microlensing. This technique depends on an effect predicted by Albert Einstein's theory of general relativity, in which a foreground star magnifies a more distant one. If the nearer star harbors a planet, the planet's gravity can distort the background star's light further and thereby betray its presence. Because the chance alignment needs to be precise, and the brightening lasts only a brief time, astronomers need to monitor millions of stars to catch microlensing events in progress.

Three recently discovered super-Earths orbit the star HD 40307.

In 2006, a large team of astronomers led by Jean-Philippe Beaulieu at the Institute of Astrophysics in Paris announced its discovery of a 5.5-Earth-mass planet orbiting a dwarf star some 20,000 light-years from Earth. The planet lies roughly 2.5 times farther from its star than Earth does from the Sun. While the Doppler and transit techniques excel at finding planets close to their stars, microlensing favors the detection of super-Earths farther out. This particular planet — dubbed OGLE 2005-BLG-390Lb — almost certainly lies in a deep freeze. Its surface temperature probably approaches that of Pluto, given its distance from the faint parent star.

How to build a planet

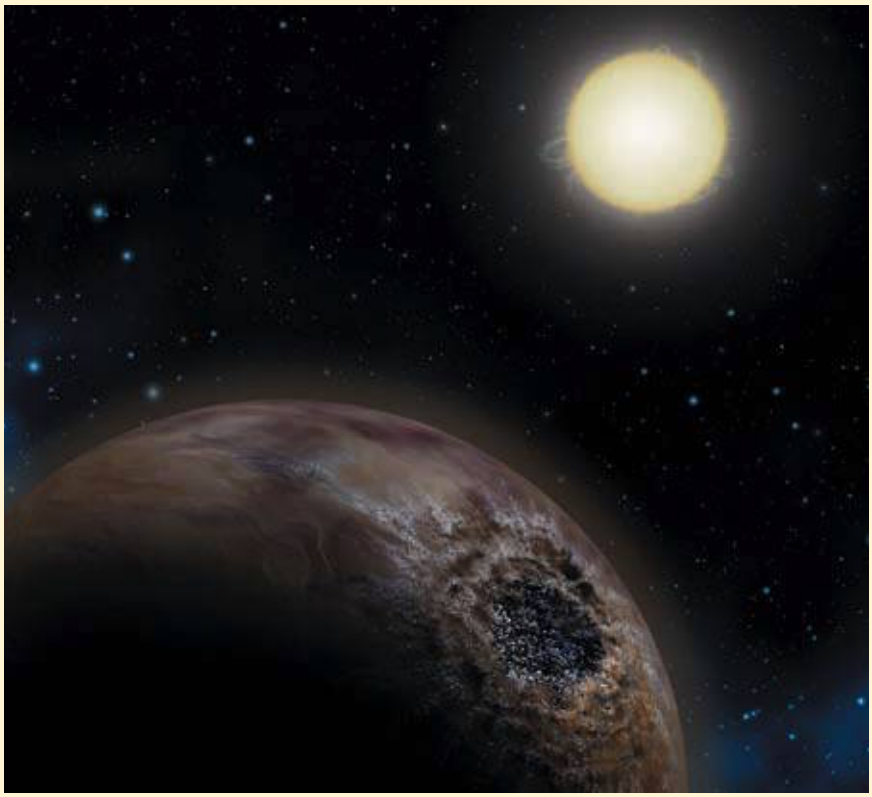
Astronomers have identified only a handful of super-Earths so far. Still, many researchers think they will prove to be more common than gas giants. The reason: Small, rocky planets should build up more easily in the protoplanetary disks that surround young stars. Besides, red dwarfs are the most common type of star in our galaxy, and their low-mass disks favor the formation of lighter planets.

In the widely accepted "core-accretion" model, solid particles first coagulate into planetary cores. These cores then accumulate gas from the surrounding disk if they grow massive enough before the gas disperses. Theorists aren't certain what the threshold is for accreting and retaining a hydrogen envelope, but they estimate it to be about 10 Earth-masses. This sets an upper limit on how massive a super-Earth can grow before it turns into a cousin of Neptune.

If super-Earths are common, why doesn't our solar system have one? Dimitar Sasselov of Harvard University thinks it's probably a matter of coincidence. "But," he adds, "it's possible that Jupiter prevented the formation of a more massive terrestrial planet in our case."

Super-Earths probably come in two main flavors: rocky, earthlike planets and ocean planets, in which water or ice makes up more than one-tenth of the mass. The rocky planets still could host oceans, as does Earth, where water accounts for only 0.05 percent of its total mass. Both planet types would contain

A diamond in the rough



Planets with diamond layers could lurk in our galaxy. Astronomers suspect such exotic worlds would form if their protoplanetary disks contained a much larger proportion of carbon to oxygen than our early solar system. Lynette Cook

Our solar system's terrestrial planets consist mostly of silicon-oxygen compounds called silicates, which come in a variety of forms such as quartz and feldspar. That may not be true of all exoplanets. Some low- and intermediate-mass planets, including super-Earths, may form substantially from carbon compounds and could contain layers of diamond. That's the intriguing suggestion by Marc Kuchner of NASA's Goddard Space Flight Center and Sara Seager of the Massachusetts Institute of Technology.

If a protoplanetary disk around a young star contains an excess of carbon or little oxygen, then carbon compounds like carbides (a hardy ceramic) and graphite (found in pencil lead) can condense out of the gas instead of silicates. Under high pressure, graphite would turn into diamond and could form layers of it many miles thick. These planets could have iron cores, tar-covered surfaces, and atmospheres rich in hydrocarbons and carbon monoxide. "Such planets are likely to be rare, because you need an overabundance of carbon relative to oxygen in the disk for them to form," says Dimitar Sasselov of Harvard University.

Kuchner says that carbon planets could form in much the same way as certain meteorites, the so-called enstatite chondrites, in our solar system. "The chemistry of some meteorites suggests that they could have formed from large quantities of carbon-rich dust. Some meteorites even contain tiny diamonds," he explains. "All you have to do is to imagine the same mix on a planet scale."

Of course, that didn't happen around the Sun. But Kuchner's case may have received a boost recently when astronomers found that the disk around the 12-million-year-old star Beta Pictoris is particularly carbon-rich. Based on observations with the Far Ultraviolet Spectroscopic Explorer satellite, a team led by Kuchner's Goddard colleague Aki Roberge estimates that the Beta Pic disk has 9 times as much carbon as oxygen. That's quite a contrast to the Sun, which contains half as much carbon as oxygen.

Now the question is whether Beta Pic represents a different kind of planetary system — one where carbon planets might form — or whether it's just a phase all systems go through. In the latter scenario, the "excess" carbon, possibly released from asteroids and comets, likely would be swept away by strong stellar winds. — *R. J.*

solids, like silicates and metals, and volatiles, such as water and ammonia. You also would expect to find trace amounts of hydrogen and noble gases.

Not long after a super-Earth forms, heavier compounds like iron alloys would settle into a core and the volatile substances would precipitate above a silicate mantle. If the planet possesses lots of water, most of it would likely be under high pressure and in the form of ice — even at high temperatures. Because ice has a lower density than silicates, an ocean planet would be bigger than a rocky planet of the same mass. Calculations by Sasselov and his colleagues Diana Valencia and Richard O'Connell, also of Harvard, show that astronomers could tell whether a super-Earth is a rocky or ocean planet if they could measure its mass to an accuracy of 10 percent and its diameter to within 5 percent.

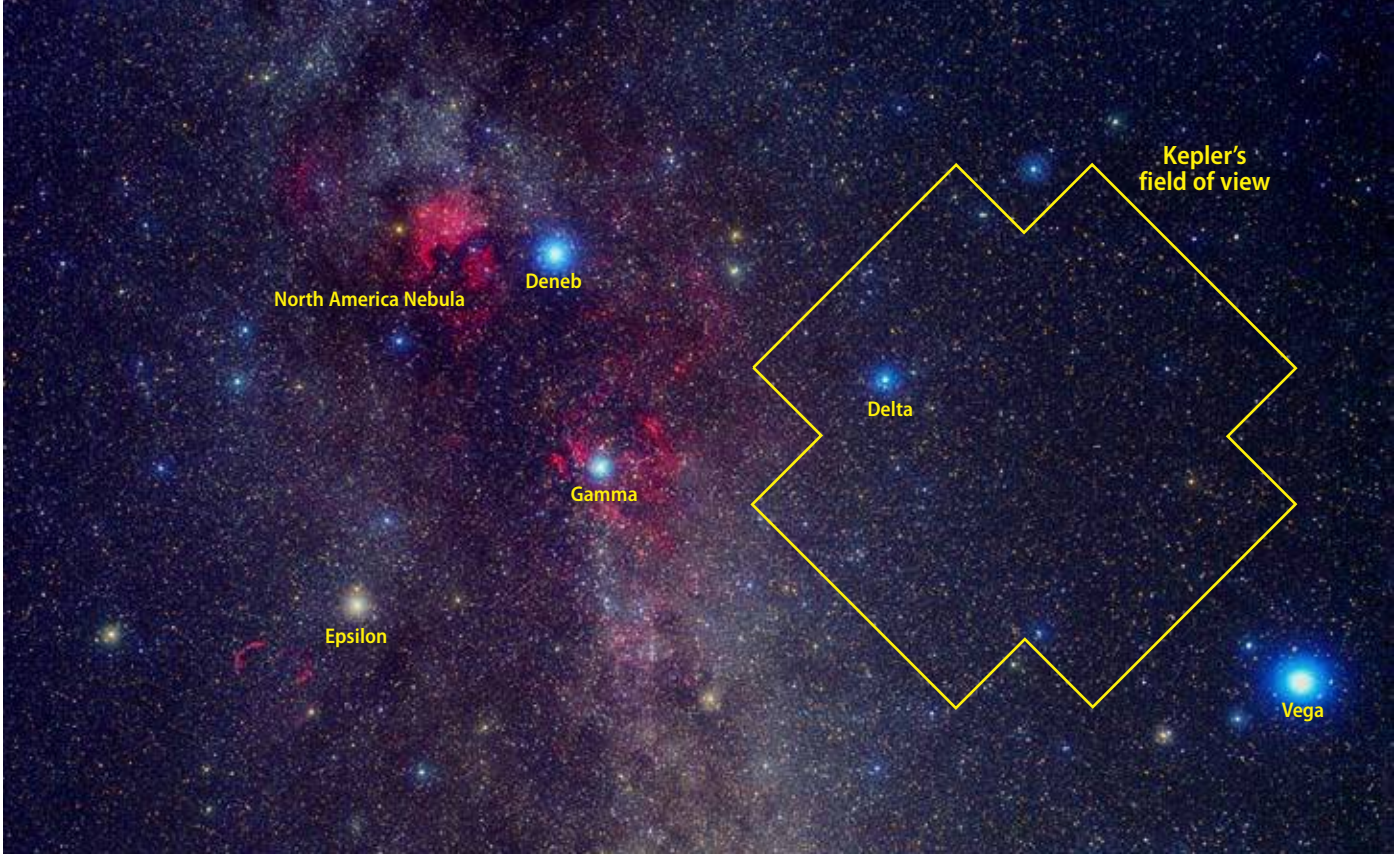
None of the super-Earths found so far transits its parent star. So, astronomers can't measure their diameters to infer their bulk compositions reliably. Theory suggests that the super-Earths around Gliese 876, Gliese 581, HD 40307, and HD 181433 all formed beyond the "snow line" of their star systems, where water freezes and accretes easily into planetary cores. Only later did they migrate inward. As they approached their stars, some of the surface ice may have melted. The OGLE 2005-BLG-390Lb planet remains stuck in the frozen outskirts.

On the prowl for life

Could any of the known super-Earths be habitable? That question is still open to debate. The two planets around Gliese 581 have received the most attention. According to a theoretical study led by Franck Selsis of the University of Lyon in France, the inner, 5-Earth-mass planet receives 30 percent more energy from its star than Venus does from the Sun.

Such a world would be unlikely to have liquid water, unless highly reflective clouds cover most of its dayside and prevent water's complete vaporization. That system's outer super-Earth plausibly could have a climate akin to early Mars. It might be able to host surface water if a "super-greenhouse" effect were in play.

Independently, Werner von Bloh of the Potsdam Institute for Climate Impact Research and his collaborators estimate



Kepler will search between the bright stars Deneb and Vega after it launches in 2009. The spacecraft will target this limited region and survey 100,000 stars, looking for dips in brightness that would signal transiting planets. Astronomers expect Kepler to find 100 or more super-Earths. Bill and sally Fletcher

that the outer planet could sustain a photosynthetic biosphere. It only needs to be geologically active enough to release carbon dioxide from its interior into the atmosphere. Their conclusion: "Despite the adverse conditions on this planet, at least some primitive forms of life may be able to exist on its surface."

Whether these particular planets are habitable or not, super-Earths found in the future may be excellent targets to search for biomarkers. Although most researchers focus on earthlike planets as potential habitats, Sasselov thinks super-Earths may offer better odds. "In my opinion, super-Earths are the best places to look for life," he says.

Plate tectonics stabilizes Earth's climate, and may be essential to life.

Getting life off a plate

The reason has to do with plate tectonics. On Earth, plate tectonics slowly moves large chunks of the planet's outer layers. Where these plates run into each other, mountain ranges build up. The process also enables complex chemistry and the cycling of substances like carbon dioxide among the atmosphere, ocean, the crust. This all makes a stable climate possible. Many scientists think plate tectonics is essential to life on Earth.

Calculations by Valencia, Sasselov, and O'Connell suggest that super-Earths likely would harbor thinner plates under more stress. This would foster more vigorous geologic activity and, in turn, more efficient and possibly faster recycling of nutrients between the planet's interior and exterior. Earth may be barely above the threshold for plate tectonics. Even though Venus has more than 80 percent of Earth's mass, it is tectonically inactive. "Bigger is better when it comes to the habitability of rocky planets," Valencia concludes.

That is good news for planet hunters, because more massive planets are easier to detect. The California-Carnegie team is building the Automated Planet Finder, a dedicated 2.4-meter telescope, at California's Lick Observatory. Its spectrograph will detect velocities as low as 2.2 mph (3.6 km/h).

On the space front, NASA plans to launch the Kepler mission in early 2009. It will observe some 100,000 stars looking for planetary transits. Astronomers expect it to find a few hundred super-Earth candidates. The challenge will be to disentangle planetary transits from unrelated brightness dips — like star spots or grazing eclipses by stellar companions — that can mimic a planet's signal.

Perhaps 100 of these candidates will orbit stars bright enough for follow-up spectroscopic observations by large ground-based telescopes. Once astronomers measure the wobble in the star's motion caused by the planet's gravity, they'll be able to infer the planet's mass.

The search for life — even indirect evidence — probably will have to await the James Webb Space Telescope (JWST). This infrared-optimized, 6.5-meter instrument is scheduled for launch in 2013. Just as the Spitzer Space Telescope allows astronomers to measure temperatures and detect water and other molecules in the atmospheres of transiting hot Jupiters, JWST may do the same for super-Earths. The trick will be to look for planets whose atmospheric characteristics stand out from the rest. Sasselov, for one, is optimistic: "Life is adaptive, and co-opts its environment. Sooner or later, we'll see the bio-signatures in a super-Earth."

Learn how astronomers hunt for exoplanets at www.astronomy.com/toc.

Are these space rocks from Mercury?

Angrite meteorites, rare and ancient, date to the birth of the solar system. Did a

by Thomas H. Burbine, Jr.

You can buy almost anything on eBay. Recently, I heard that someone was selling a potato chip shaped like Abraham Lincoln's head. Opening bid: 2 cents. But I logged on to the site to check prices on a material quite unlike deep-fried potatoes and much more valuable: rare meteorites called angrites.

Small samples of an angrite called NWA 2999 were being auctioned to the highest on-line bidder. The meteorite fell to Earth in northwest Africa, hence its "NWA" label. Meteorite collector Greg Hupe from Lake

According to a controversial idea, angrite meteorites are pieces of Mercury blasted into space billions of years ago by an impact. Speculation about a Mercury origin has fed collectors' interest in angrites. Small chips of the angrite NWA 2999 (inset) have recently turned up for auction on eBay. Lynette Cook for *Astronomy;* INSET: Greg Hupe/The Hupe collection

large asteroid give birth to them — or did they come from the innermost planet?

Meteorite hunters found these space rocks, dubbed NWA 4590, near the Morocco-Algeria border In June 2006. NWA 4590 is a 4.56-billion-year-old angrite. Gregory M. Hupe/The Hupe collection

Placid, Florida, recovered 5.3 pounds (2.4 kilograms) of the space rock in 2004.

In recent years, the overall prices of angrites like NWA 2999 have risen because of an as yet unproven hypothesis: that angrites are actually fragments of rock that originated on Mercury. Sellers on eBay know the Mercury connection is an enticement to buyers. Perhaps that's why the ones offering the NWA 2999 samples included "A possible Mercury connection?" and "The case for samples from Mercury!" in their on-line auction listings.

But the case for angrite origins on Mercury is hardly proven, even though these meteorites remain hot items. I've studied both angrites and Mercury, and I'm not convinced they are related.

Right now, I think the evidence points to an asteroid as the possible source, or "parent body," for angrites. Most meteorites are refugees from the asteroid belt, and for now it looks like this is also the case for angrites.

Interest in the Mercury connection remains strong despite the debatable nature of the evidence. But soon we may have a clearer answer. In 2011, the MESSENGER spacecraft will enter orbit around Mercury. Among other things, MESSENGER will map the chemical composition of Mercury's surface rocks. The new data may help resolve lingering uncertainties about angrite origins.

Rocks from Mars

The idea that meteorites could have came from Mercury, a planet quite distant from Earth, is not as far-fetched as it sounds. We have already recovered many meteorites that originated on the Moon and Mars.

Meteorites from other solar system bodies are of great scientific value. Physical samples enable us to perform detailed laboratory studies of their chemistry and mineral composition, something that's not possible with a spacecraft or robot lander. Physical samples tell us a lot about the moon or planet the meteorite came from. It's the next best thing to going there.

The journey of a martian or lunar meteorite to Earth begins violently, with an impact from an asteroid or comet. Fragments of debris from the impact traveling fast enough can escape into space, where they assume looping elliptical orbits around the Sun. If the fragment is smaller than 33 feet (10 meters) in diameter, astronomers usually call it a meteoroid.

Some meteoroids eventually cross Earth's orbit and are captured by the planet's gravity. The smallest meteoroids that fall into Earth's atmosphere burn up, creating a bright streak of light — a meteor. If the fragment is large or dense enough to survive reentry and turns up on the surface, it's earned the right to be called a meteorite.

It's theoretically possible for an impact to eject meteorites from Mercury and have them end up on Earth. Compared to other types of meteorite, however, angrites would be uncommon — representing perhaps a few percent of all meteorite-falls on Earth.

Meteorite identification

Scientists can often connect a meteorite to its source because solar system bodies have distinctive chemical and mineral compositions. The various members of the solar system formed at different distances from the Sun, and therefore under different conditions.

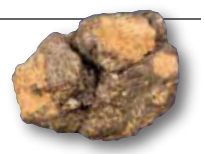
The compositions of meteorites also reflect the conditions in which they formed. We have identified more than 50 meteorites from the Moon and more than 30 from Mars. The identification of lunar meteorites owes its success to the Apollo program.

Astronauts collected numerous physical samples for detailed analysis. Such studies allowed us to make the connection between the lunar meteorites and their source.

Moon rocks, lunar scientists discovered, come in two basic flavors. The light-colored lunar highlands are rich in a mineral group called plagioclase. The highlands are part of the original lunar crust, which formed as the molten body cooled.

The second type of Moon rock comes from the darker lunar seas or "maria." Here, the rocks' building blocks tend toward iron-rich forms of the minerals pyroxene and olivine. The maria formed when volcanism melted rock in the lunar mantle — the layer below the crust — and erupted it onto the surface.

Angrites are rare — perhaps a few percent of all meteorite-falls on Earth.



Meteorites from other worlds

ALH84001 is the best-known meteorite from Mars. Some scientists think this 5-inch-wide (12 centimeters) rock contains microscopic fossils of martian life. NASA/Johnson Space Center

MAC88105 is a lunar meteorite found in Antarctica's MacAlpine Hills ice field. Up to 40 percent of debris escaping the Moon's gravity will eventually fall on Earth. NASA/Johnson Space Center

This basketball-size object on Mars, dubbed Heat Shield Rock, was the first meteorite ever identified on another planet. It may be debris from an asteroid strike. NASA/JPL/Cornell

The first lunar meteorite ever discovered, ALHA81005, fell in Antarctica. In 1983, Brian Mason of the Smithsonian Institution and NASA's Roberta Score determined that ALHA81005's mineral profile closely resembled that of Moon rocks brought back by the Apollo astronauts.

It has been more difficult to link meteorites found on Earth to Mars. Although we didn't have physical samples of the planet study, experiments by the Viking landers taught us enough about martian rocks to link them to Antarctic meteorites.

Researchers initially made the connection on the basis of the meteorites' crystallization ages — the ages at which they solidified from molten rock. Asteroids cooled and solidified about 4.56 billion years ago with the rest of the solar system. This is why meteorites that originate from asteroid collisions are commonly around 4.56 billion years old.

But the suspected martian meteorites from Antarctica had crystallization ages of less than 1.4 billion years, long after any asteroid had a molten surface. This is not true of Mars, however. Being much larger than any asteroid, Mars took longer to cool after its initial formation 4.56 billion years ago. Volcanic activity on Mars could have produced the 1.4-billion-year-old rock that eventually found its way to Earth and fell on Antarctica.

Donald D. Bogard and Pratt Johnson of NASA's Johnson Space Center provided the confirmation that the meteorites came from Mars. Their research showed that gas trapped in bubbles in the Antarctic meteorite EETA79001 matched measurements of the Mars atmosphere from the Viking landers.

EETA79001 was only the first. Additional martian meteorite identifications followed, based on the Viking atmospheric gas data. Research also demonstrated that the meteorites contain a distinctly martian mixture of oxygen isotopes.

Strange space visitors

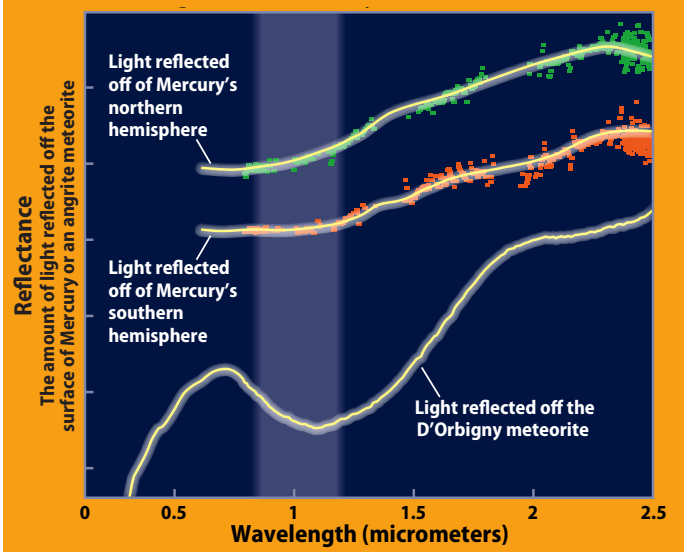
We have no physical samples of Mercury — nor even detailed spacecraft data about its surface geology. It's not possible to put angrites to the same rigorous test as the lunar and martian meteorites.

But even without the Mercury connection, angrites are still special rocks. For one thing, they are rare. Approximately 16 have been found. They are also extremely old, dating to the very beginning of the solar system.

Angrite mineral chemistry is also unusual. Like all rocks, meteorites contain a jumble of different minerals. The types and amounts of minerals in a particular kind of rock depend on factors like the chemistry of the source materials and how quickly they crystallized.

The basic mineral recipe for an angrite includes black or purple grains of pyroxene, grayish grains of plagioclase, and greenish grains of olivine. Angrites are stony meteorites, so it's rare to find iron-nickel metals in them.

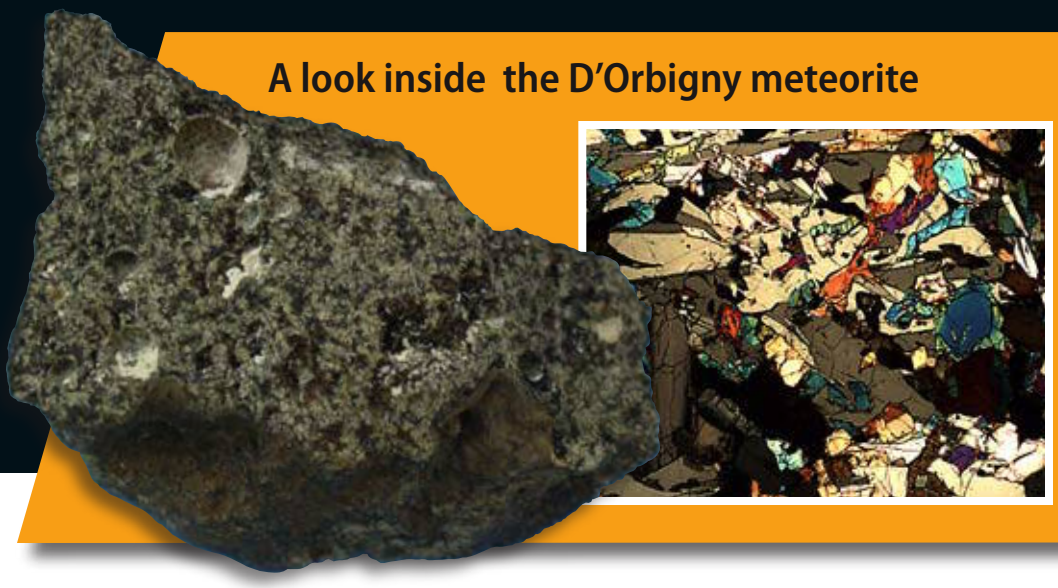
Do angrite meteorites and Mercury reflect light the same way?



This diagram compares the ways Mercury and the D'Orbigny angrite meteorite reflect light at different wavelengths. The red and blue points near the top are the reflectance spectrum of Mercury's surface. The curved line below it represents a reflectance spectrum of the D'Orbigny angrite meteorite.

D'Orbigny absorbs infrared light strongly at 1 micrometer, creating a pronounced dip in its spectrum. But Mercury's reflectance spectrum does not dip. This suggests the planet's surface contains a different type of rock. *Astronomy*: Theo Cobb; Mercury data: Johan Warell (Uppsala University)

A look inside the D'Orbigny meteorite



Sliced thin and examined under a microscope, a sample (left) of the angrite meteorite D'Orbigny highlights the mix of minerals within. Bluish-colored crystals are mainly olivine. Brown- and tan-colored grains are mainly pyroxene. The grayish-white or gray-brown minerals are plagioclase. Cascadia Meteorite Laboratory/Portland State University

The relatively high abundance of plagioclase tells us angrites formed from a volcanic rock called basalt. Chemically, angrites are similar to the dark gray lava that erupts from Hawaiian volcanoes.

But what really distinguishes angrites from other meteorites is the chemical composition of their minerals. Most meteorites contain minerals rich in iron and magnesium. The minerals in angrites, however, are rich in aluminum, titanium, and calcium. This chemical recipe is unlike any found in other types of meteorites.

The case for Mercury

The ultimate question for angrite enthusiasts is whether these unusual meteorites acquired their strangeness on Mercury or on an asteroid. Since 2005, meteorite researchers Anthony Irving and Scott Kuehner of the University of Washington have argued that angrites may have originated on Mercury. They have offered various kinds of circumstantial evidence.

One possible piece of evidence for a Mercury origin is that angrites are depleted in volatiles — chemical elements with low boiling points, like sodium. The lack of volatiles is consistent with angrites forming close to the Sun, as on Mercury, where hot conditions would prevent volatile elements like sodium from becoming part of crystallizing rock.

To support a Mercury origin, Irving and Kuehner also cite cosmic ray exposure ages of angrites, which tell us how long a particular meteorite remained in space before falling to Earth. The clock starts when the rock is liberated from its parent body, either by a collision between two asteroids or a violent impact.

For whatever period the rock drifts in space exposed, cosmic rays — a form of radiation — strike its surface. The radiation leaves a measurable chemical trace that tells us the exposure time.

Cosmic ray exposure ages for angrites vary from 200,000 to 56 million years. Irving and Kuehner argue that the wide range in ages suggests the angrite parent body was large enough to survive repeated impacts. With a diameter of 3,030 miles (4,880 kilometers), Mercury certainly fits this description.

Proving the case

The arguments possibly linking angrites to Mercury suffer from the same flaw: they do not rule out asteroids. For example, an asteroid parent body could have formed close to the Sun and therefore would be poor in volatile elements. Similarly, a large asteroid could survive multiple collisions or impacts and produce fragments with a variety of cosmic ray ages.

The data we have for Mercury's surface composition also present a challenge. This information comes from studies of visible and near-infrared light reflected off Mercury's surface. The minerals in one type of rock absorb or reflect different wavelengths than others. This provides a distinctive light fingerprint called a reflectance spectrum.

Because of the type of iron minerals in angrites, they absorb visible and infrared strongly at a wavelength of 1 micrometer. The existence of this distinctive "absorption band" allows us to tell if surface rock on Mercury is enriched with the same kind of iron as angrites. We simply compare the reflectance spectra of angrite meteorites in the laboratory with the reflectance spectrum of Mercury's surface seen from telescopes or spacecraft.

Johan Warell of Uppsala University in Sweden has collected such a spectrum of Mercury using a telescope. It shows that the planet's surface reflects little to no light at 1 micrometer. This suggests Mercury's surface rocks may be low in the type of iron found in angrites.

The crystallization ages of the angrites also undermine the case for a Mercury origin. Angrites solidified about 4.56 billion years ago, making them some of the oldest rocks in the solar system. In fact, angrites formed only 3 to 4 million years after the oldest known solid rock materials in

Angrite chemistry is weird, unlike that of any other type of meteorite.

Thomas H. Burbine, Jr., *is a professor in the department of physics and astronomy at Bates College in Lewiston, Maine.*

Algerian desert dwellers found this angrite, NWA 4801, and sold it to meteorite dealer Greg Hupe. Gregory M. Hupe/The Hupe collection

This electron microscope image of a tiny sample of angrite LEW 87051 highlights needlelike grains of the mineral feldspar. The grains formed as the minerals rapidly solidified from molten rock. Takashi Mikouchi

the solar system. Asteroids, too, date to 4.56 billion years.

Mercury's surface, however, is not as old as asteroids or angrites. Even a relatively small planet like Mercury would take longer to cool and solidify than the vast majority of asteroids. This is why the ancient age of angrites points to an asteroid, not a planet, as the parent body.

MESSENGER at Mercury

In 2011, the MESSENGER spacecraft will begin to study Mercury from orbit. The only spacecraft that has previously flown by Mercury was Mariner 10 in 1974. It imaged only about half the surface.

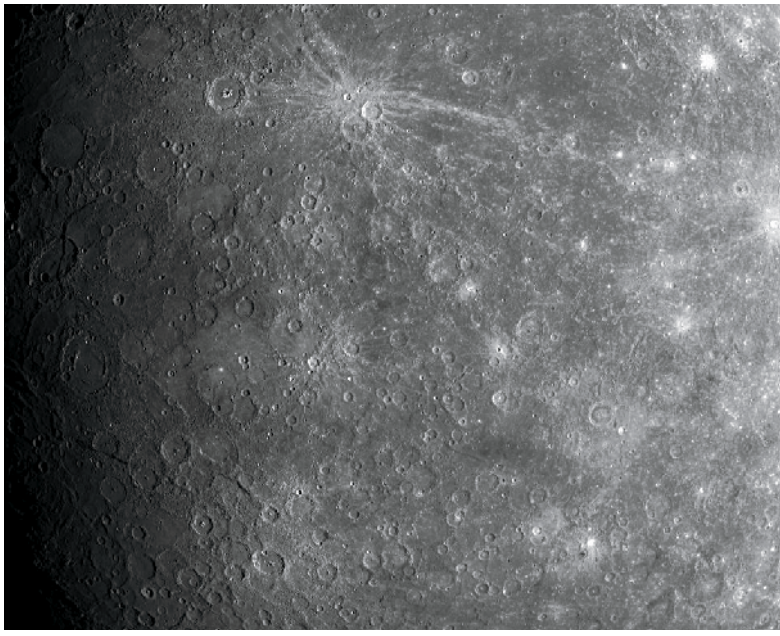
MESSENGER will obtain reflectance spectra for large tracts of Mercury's surface. Areas with spectra similar to that of angrites should be distinctive. MESSENGER'S X-ray spectrometer could measure the abundance of various elements in Mercury's surface rock. It should be easy to identify areas enriched, like angrites, in aluminum and titanium. Or not.

MESSENGER's exploration of Mercury will be at a distance and skin deep. It could leave us in uncertainty. It's conceivable that angrite source rock is present on limited parts of Mercury's surface, and therefore do not contribute very strongly to the planet's reflectance spectrum.

Another possibility: The angrite source rock lies beneath the surface, and then MESSENGER would not see it at all. Perhaps the few angrites we have were subsurface rock blasted into space by impacts.

We see a similar scenario for the martian meteorites. They consist of igneous rock, formed underground from cooling molten rock. Yet a significant portion of Mars' surface is covered by sedimentary rock, which forms near the surface. Either martian sedimentary rocks did not survive the ejection process, or we have simply failed to identify martian meteorites made of non-igneous rock.

Right now, lack of any data that conclusively proves or refutes the Mercury origin for angrites leaves things in a muddle. As in a legal trial, arguing a case based entirely on circumstantial evidence can raise as many questions as it attempts to answer.



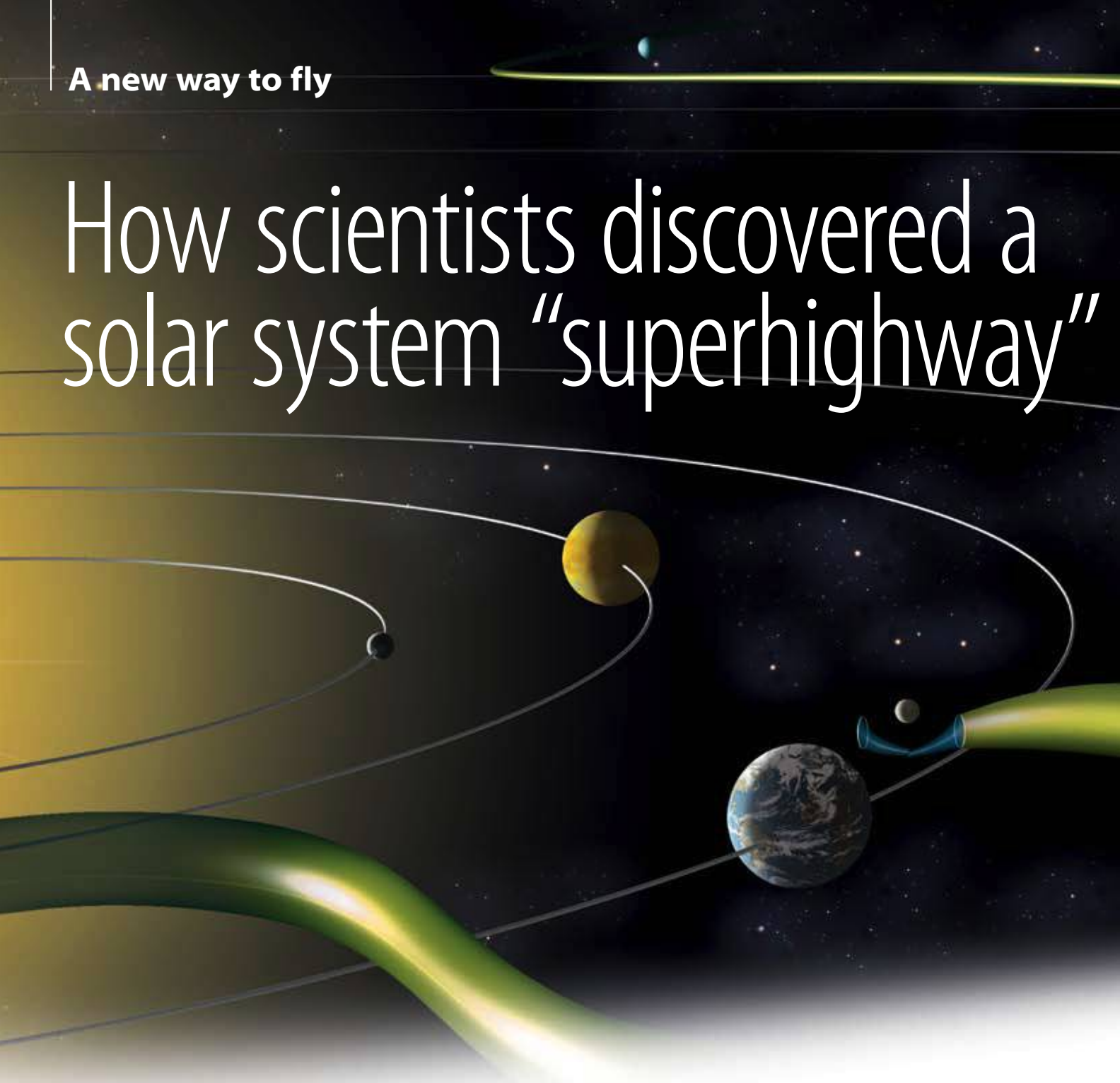
On January 14, 2008, the MESSENGER spacecraft imaged this previously unseen side of Mercury during a brief flyby. Once the craft enters its final orbit of Mercury in 2011, it may send home new information bearing on the question of whether angrite meteorites originated on Mercury.

NASA/Johns Hopkins University Applied Physics Laboratory/Carnegie Institution of Washington

Judging from the evidence at hand, I do not think angrites originated on Mercury, but instead are fragments of asteroids. Just to cite some recent evidence: Andrew Rivkin at Johns Hopkins University has determined that the asteroid 5261 Eureka has a reflection spectrum similar to that of angrites. This appears to confirm an asteroid link but doesn't prove the case. I will keep an open mind until I see the MESSENGER results.

Learn how to tell an ordinary rock from a possible meteorite at www.Astronomy.com/toc.

How scientists discovered a solar system "superhighway"



By riding planetary gravity, spacecraft can explore the solar system without using fuel. **by Francis Reddy**

During the past decade, researchers working to improve how spacecraft navigate have discovered an underlying structure in the solar system. But it isn't the vast cosmic clockwork that English physicist Sir Isaac Newton envisioned, with planets and moons orbiting the Sun in stately precision.

Instead, this new solar system is a complex, dynamic structure of swirling and interconnecting pathways shaped by the mutual gravitation of all the planets and moons. These passages constitute a natural transportation network that enables anything — dust, meteorites blasted off of planets, asteroids, comets, and spacecraft — to move throughout the solar system with ease. "We call it the Interplanetary Superhighway," says Martin Lo, a researcher at NASA's Jet Propulsion Laboratory (JPL) in Pasadena, California.

Many spacecraft have already traveled the Interplanetary Superhighway (IPS). They include NASA's Genesis and

Spacecraft can travel far and wide in the solar system by riding gravitational currents between every planet and moon. Gravity does the heavy lifting on these journeys, so the craft can carry less propellent. *Astronomy:* Roen Kelly

Wilkinson Microwave Anisotropy Probe (WMAP) spacecraft, and the European Space Agency's SMART-1 lunar orbiter.

The IPS is no expressway: Even though missions save fuel, they can take much longer to reach a target than they would by using chemical rockets. However, if you're willing to wait, a longer journey results in big savings of a spacecraft's most precious commodity: propellant. And that means science probes could travel farther afield at lower cost, opening up new possibilities for exploration in virtually any destination in the solar system.

Easy rider

Key factors dictate the fuel needs for conventional spacecraft missions. "It depends on how far apart the destinations are that you want to visit, the length of time you want to stay there, and the number of instruments you carry on board," says engineer Shane Ross at Virginia Tech in Blacksburg, Virginia. Ross worked with Lo in mapping out the IPS.

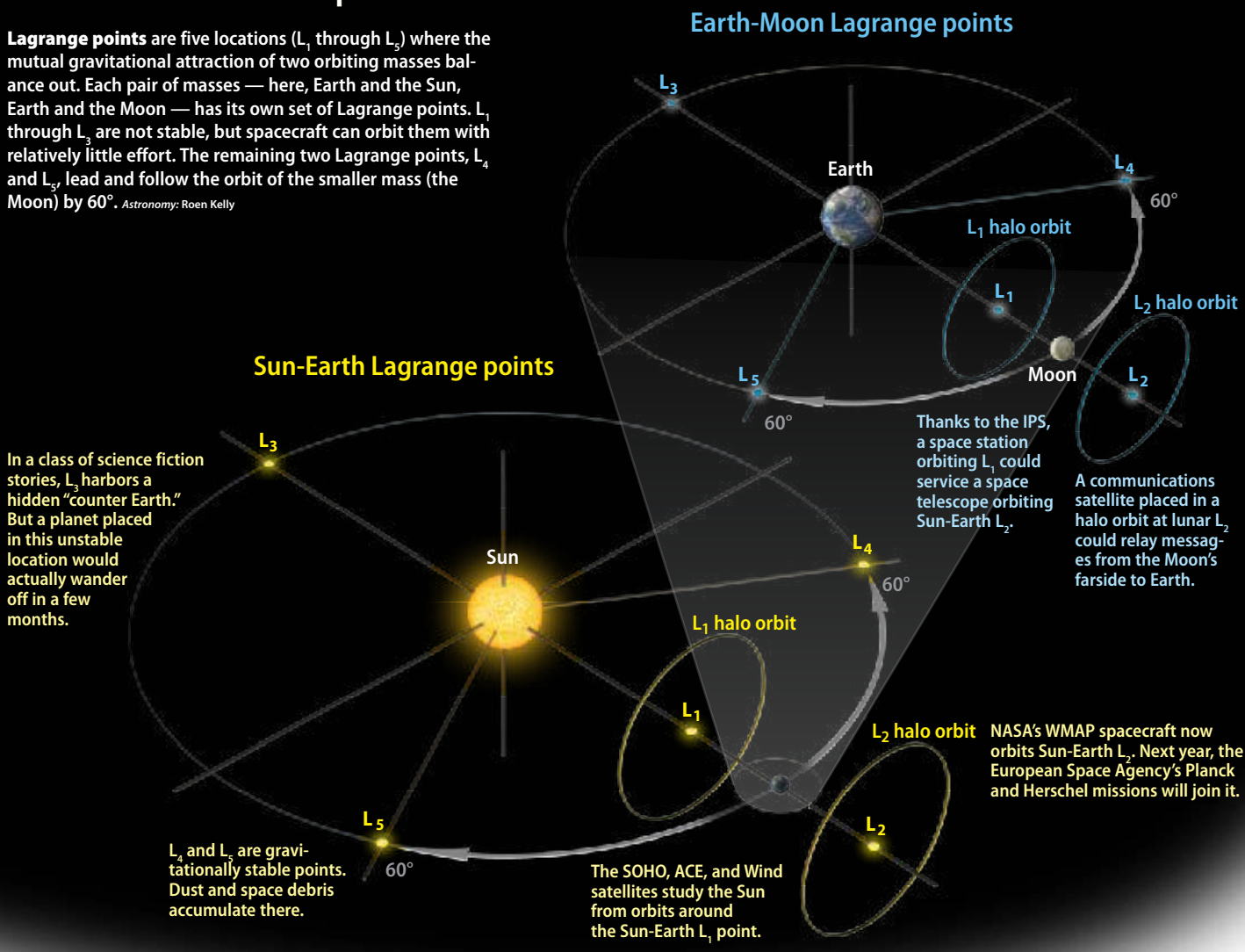
Take, for example, Voyager 1, now the farthest and fastest spacecraft in the solar system. Fuel made up nearly half of its initial mass. Although JPL mission planners used gravitational boosts to speed Voyager from Jupiter to Saturn and then out of the solar system, the craft still had to burn propellant to fine-tune its trajectory. The fuel problem gets worse for orbiters and landers, which must bleed off much of their original speed when they reach their destinations.

The IPS provides a way around this. Now it's possible to design trajectories that take advantage of the complex interplay of gravitational forces from multiple planets and moons. The resulting passages follow what are, in essence, gravitational currents that flow throughout the solar system.

The IPS can take spacecraft anywhere, Ross says. "If you launch from the surface of any planet or moon with the right

Gravitational balance points

Lagrange points are five locations (L_1 through L_5) where the mutual gravitational attraction of two orbiting masses balance out. Each pair of masses — here, Earth and the Sun, Earth and the Moon — has its own set of Lagrange points. L_1 through L_3 are not stable, but spacecraft can orbit them with relatively little effort. The remaining two Lagrange points, L_4 and L_5, lead and follow the orbit of the smaller mass (the Moon) by 60°. *Astronomy:* Roen Kelly


Earth-Moon Lagrange points
L3
Earth
L4
60°
L1 halo orbit
L1
L2 halo orbit
Moon
L2
L5
60°
Thanks to the IPS, a space station orbiting L1 could service a space telescope orbiting Sun-Earth L2.
A communications satellite placed in a halo orbit at lunar L2 could relay messages from the Moon's farside to Earth.
Sun-Earth Lagrange points
In a class of science fiction stories, L3 harbors a hidden "counter Earth." But a planet placed in this unstable location would actually wander off in a few months.
L3
Sun
L4
60°
L1 halo orbit
L1
L2 halo orbit
NASA's WMAP spacecraft now orbits Sun-Earth L2. Next year, the European Space Agency's Planck and Herschel missions will join it.
L5
L2
L4 and L5 are gravitationally stable points. Dust and space debris accumulate there.
60°
The SOHO, ACE, and Wind satellites study the Sun from orbits around the Sun-Earth L1 point.

speed and direction, or start in the right orbit around any planet or moon, you can eventually get to the surface or in orbit about any other planet or moon." The IPS can even take probes out of the solar system, given enough time.

Balance points

Lo, Ross, and Caltech's Jerrold Marsden and Wang Sang Koon began mapping out the IPS using key ideas from various branches of mathematics. One is the existence of gravitational balance points between any two orbiting bodies.

For every pair of masses, their gravitational forces strike a balance at five locations. Two of these spots are so stable they can trap dust or asteroids. Although the other locations are unstable, mission designers realized decades ago that spacecraft can maintain orbits around them with little effort.

Scientists discovered these balance points in the 18th century. The Swiss mathematician Leonhard Euler (1707–1783) identified the first three, dubbed L1, L2, and L3. These points lie along a line joining the two orbiting masses.

Later, French mathematician Joseph-Louis Lagrange (1736–1813) discovered two more balance points: L4 and L5. They lie along the orbit of the smaller mass, leading and following its motion by 60°. Scientists now refer to all of these locations as Lagrange points.

Unstable options

Matter placed at L1, L2, and L3 will linger but eventually drift off — these points aren't stable. But orbital motion helps corral objects at L4 and L5. The best example: There are 2,500 Trojan asteroids ensnared at Jupiter's L4 and L5 points.

Most scientific interest has focused on L4 and L5. For example, a famous 1975 study by Princeton University's Gerard K. O'Neill determined L5 to be the preferred location for a permanent space colony.

Stability counts for a lot if you want to keep something in one spot. But if you want to travel around the solar system, the unstable Lagrange points are a lot more interesting. It's a characteristic of instability that a little change can produce a major effect down the road.

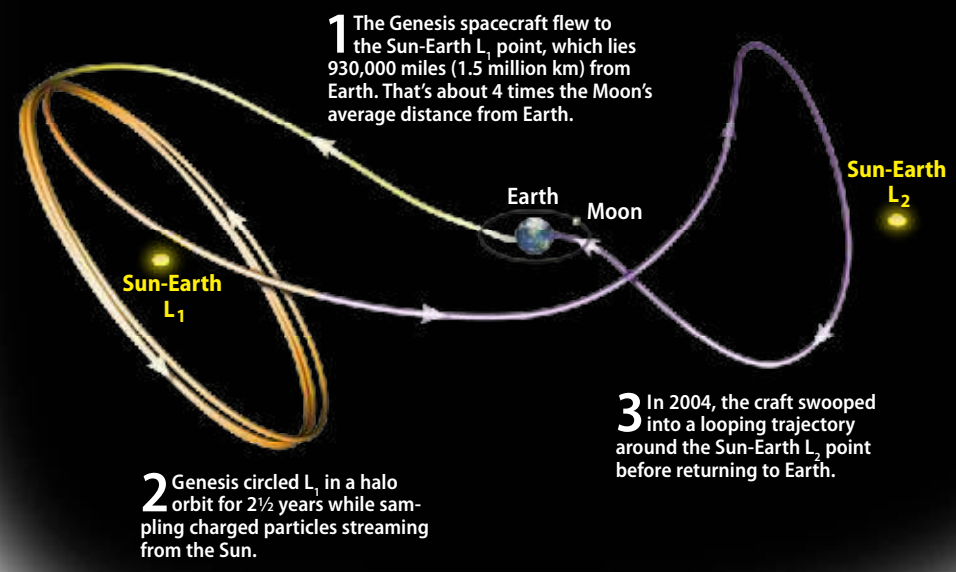
Francis Reddy *is a senior editor of* Astronomy *magazine.*

In 1961, meteorologist Edward Lorenz dubbed this sensitivity to initial conditions the "butterfly effect" after noticing that computer-based weather forecasts produced wildly different results with only slight changes in starting conditions. Carried to its extreme, he said, the flapping of a butterfly's wings in one part of the world could alter the weather in another. Mathematicians developed what they call "chaos theory" to describe such systems.

Precisely because they're dynamically unstable, the L1 and L2 points constitute the IPS equivalent of highway interchanges. Near these points, the tiniest nudge from a thruster could send a spacecraft on entirely new trajectories. "There are paths that approach the Lagrange points, orbit around them, head off on an orbit around the Sun, and then come back," Ross says. "The possibilities are mind-boggling."

Genesis' loopy journey

The Genesis mission left Earth in 2001 to sample the solar wind. It flew millions of miles using relatively little fuel by following a trajectory in which gravitational influences created a "path of least resistance" through space. *Astronomy:* Roen Kelly


1 The Genesis spacecraft flew to the Sun-Earth L_1 point, which lies 930,000 miles (1.5 million km) from Earth. That's about 4 times the Moon's average distance from Earth.
Earth
Moon
Sun-Earth L_2
Sun-Earth L_1
3 In 2004, the craft swooped into a looping trajectory around the Sun-Earth L_2 point before returning to Earth.
2 Genesis circled L_1 in a halo orbit for 2½ years while sampling charged particles streaming from the Sun.

Corraling complexity

The tools needed to make a road atlas of the IPS — and develop modern notions about mathematical chaos — began with the work of Jules-Henri Poincaré (1854–1912). The French mathematician was searching for an exact solution to the so-called three-body problem: What are the orbits of three masses interacting gravitationally in space?

He didn't find it — no one has. Thanks to the complex interplay of ever-shifting forces, the three-body problem is a tough one to solve. Even with simplifications like restricting all bodies to the same plane or making one of the masses vanishingly small, the three-body problem remains daunting. But Poincaré found a way to corral the complexity.

Poincaré saw that families of similar orbits lie on smooth surfaces called manifolds. Unless the orbiting object's energy changes — say, by firing a thruster — it forever remains on the same surface. Easy enough, but the tough part is understanding that these structures exist in six dimensions — up-down, left-right, forward-back, plus a dimension for the object's speed in each direction.

Poincaré noticed something interesting about unstable periodic orbits — the kind a spacecraft at L1 or L2 might experience. Such orbits generate tube-shaped manifolds that contain all of the paths the craft could follow to drift out of its orbit without changing energy (by, say, firing a thruster). This is the orbit's unstable manifold. And there's another tube — the stable manifold — that contains all of the paths that can place the spacecraft onto its current orbit with no energy change.

Because people live in three-dimensional space, it's hard to get your head wrapped around mathematical manifolds in a six-dimensional universe. But, in essence, these manifolds constitute the IPS' off-ramps and on-ramps.

Homing in on Lagrange

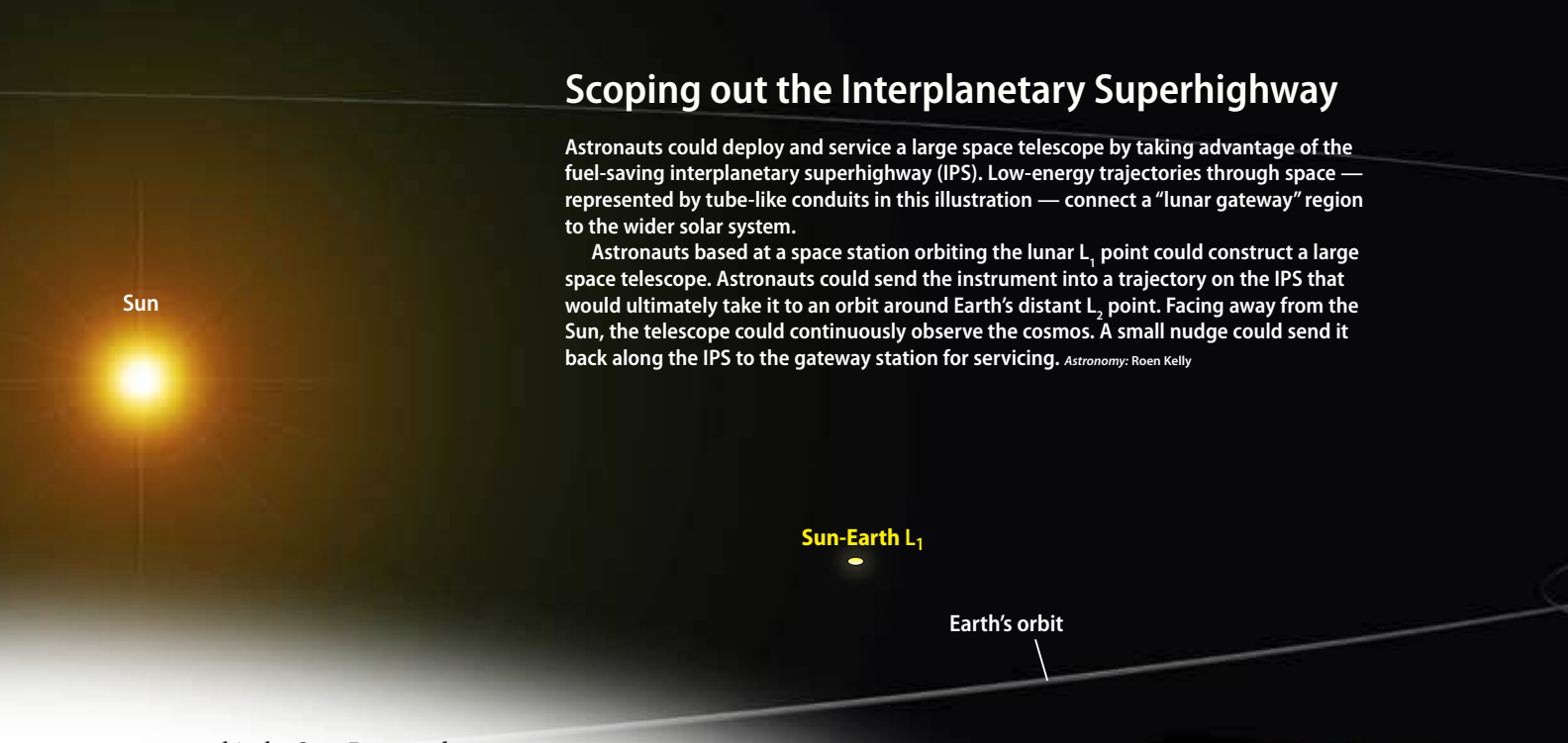
Groundbreaking on the IPS began in 1966, when Stanford University graduate student Robert Farquhar described orbits around Earth-Moon L2, the balance point behind the Moon. A satellite in such an orbit could continuously relay data and messages from Earth to the lunar farside, where communication would otherwise be impossible.

Farquhar called these paths halo orbits because, seen from Earth, a satellite would slowly trace a halo-like circle around the Moon. Seen from space, a halo orbit resembles the edge of a potato chip centered on the Lagrange point.

A few years later, Farquhar persuaded NASA to fly the first mission to a Lagrange point. His team found a pathway that placed the International Sun-Earth Explorer 3 (ISEE-3), launched in 1978, into a halo orbit at Earth's L1 point (the balance point between Earth and the Sun). This gave the spacecraft a continuous view of the Sun and allowed ISEE-3 to monitor the "wind" of charged particles streaming from it.

Without knowing it, Farquhar's team was the first to road test the IPS. Any path they chose to put ISEE-3 into a halo orbit around Sun-Earth L1 would inevitably follow this point's stable manifold. Pictured in six dimensions, the craft's orbit traced a lazy spiral around the tube's surface, naturally spooling ISEE-3 into its halo orbit. The probe could also spiral out of its halo orbit along the unstable tube.

And that's just what the mission controllers did. In 1982, with its primary mission complete, ISEE-3 went on to accomplish other goals. By combining five lunar flybys with broad loops around Sun-Earth L2, the probe gained enough



Scoping out the Interplanetary Superhighway

Astronauts could deploy and service a large space telescope by taking advantage of the fuel-saving interplanetary superhighway (IPS). Low-energy trajectories through space — represented by tube-like conduits in this illustration — connect a "lunar gateway" region to the wider solar system.

Astronauts based at a space station orbiting the lunar L_1 point could construct a large space telescope. Astronauts could send the instrument into a trajectory on the IPS that would ultimately take it to an orbit around Earth's distant L_2 point. Facing away from the Sun, the telescope could continuously observe the cosmos. A small nudge could send it back along the IPS to the gateway station for servicing. *Astronomy:* Roen Kelly

energy to orbit the Sun. Renamed the International Cometary Explorer (ICE) after its final lunar flyby, the craft became the first to directly investigate a comet in September 1985.

At about the same time, a team led by Carles Simó at Spain's University of Barcelona was seeking an easy way to get the Solar and Heliospheric Observatory (SOHO) into a halo orbit around Sun-Earth L1. They rediscovered Poincaré's orbital manifolds and developed tools to compute flight paths based on them.

Mission designers began to take notice. One of them was Martin Lo. He wondered how far these tubes extended from the Lagrangian gateways, and where they ultimately ended up. Was it possible to go from one planet to the next?

Genesis rides the IPS

At the time, Lo and Purdue University astronautical engineer Kathleen Howell were planning the trajectory for NASA's Genesis mission to return samples of the solar wind to Earth. Genesis launched in August 2001, cruised for 3 months to Sun-Earth L1, and fired its thrusters for almost 5 minutes to insert itself into a halo orbit. In December, the craft opened its collector arrays and began gathering solar wind particles. It completed five halo orbits over the next 30 months.

In April 2004, Genesis battened down its sample-collector hatch, spooled off the halo orbit, and headed home. Over the next 5 months, the craft would pass Earth and then loop behind it around Sun-Earth L2. This seemingly unnecessary back loop allowed the craft to follow the tube that would deliver the sample return capsule to a daylight landing in Utah.

Genesis proved spacecraft could use a lot less fuel if they worked with manifolds instead of thrusting through them. "The trajectory design provided an automatic halo departure and return to Earth," Lo explains. "Genesis wouldn't have needed to use any fuel at all in a perfect world. But, practically, there are always small navigation maneuvers to correct tiny errors in our knowledge of the spacecraft's speed or position."

Tube hopping

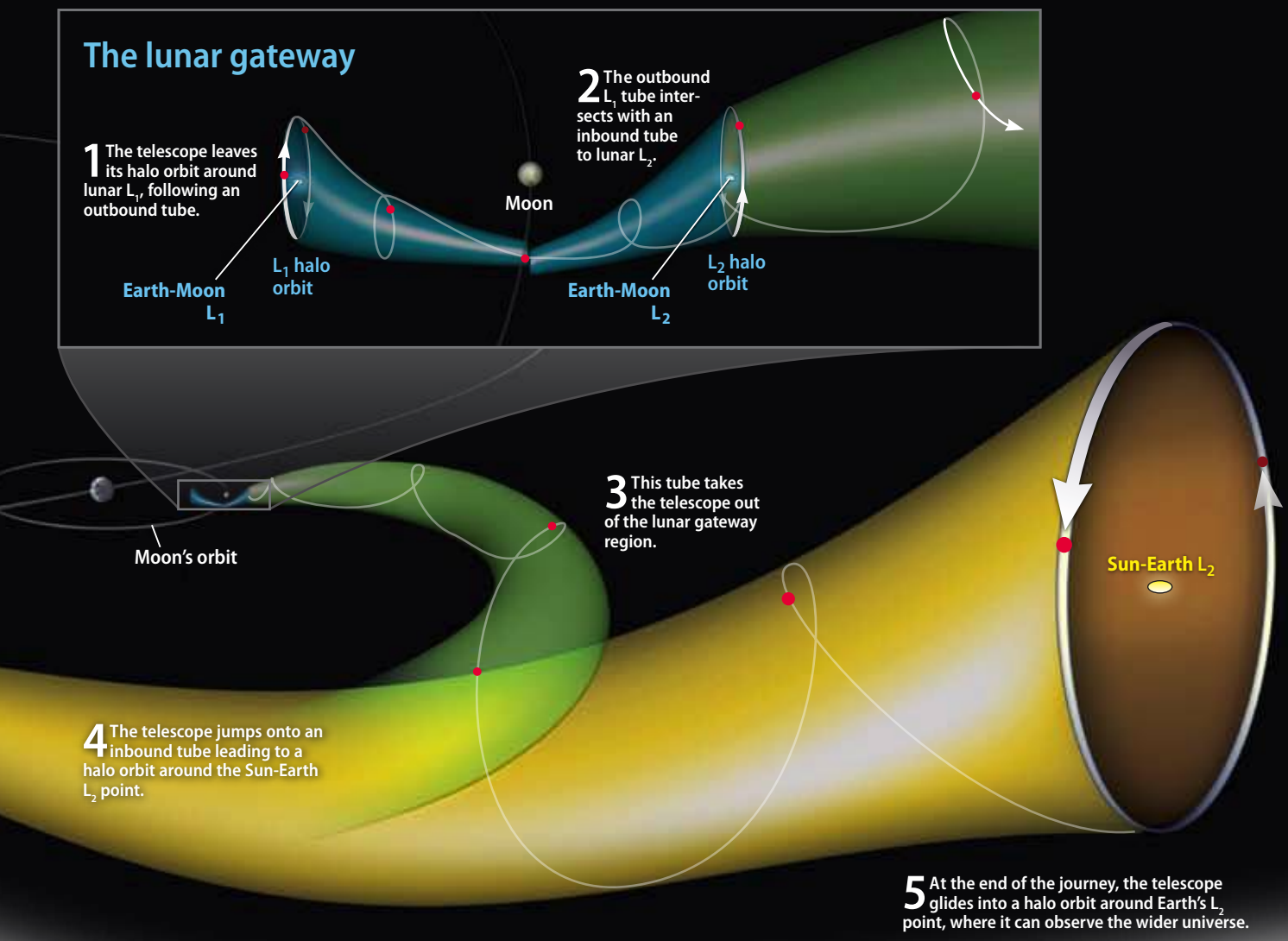
Perhaps the most exciting aspect of the IPS is this: A spacecraft can use it to easily transfer from one planet's sphere of influence to another's. Picture the manifolds arcing from each planet's Lagrange points as the swirl of water spraying from a lawn sprinkler. They're in constant motion as the planets and moons that create them ply their paths in space. When the tubes from one planet intersect those of another, low-energy transfers between the two worlds become possible.

In 1996, Lo and Ross demonstrated that tubes from Jupiter's and Saturn's Lagrange points intersected every couple of decades. Further work showed that all of the planets were so linked. Using this system, a spacecraft — or a meteorite, comet, or asteroid — could migrate from the Kuiper Belt to the asteroid belt, or vice versa, in a matter of a few hundred years.

This ability of objects to effortlessly navigate the solar system explains some puzzling behaviors. In 1943, astronomers discovered Comet 39P/Oterma orbiting inside of Jupiter's orbit. The comet circled the Sun three times for every two Jupiter orbits (a 3:2 resonance). But in 1963, Oterma swept within 9.3 million miles (15 million kilometers) of the planet and ended up in a 2:3 resonance beyond Jupiter.

It turns out that Oterma's inner orbit skirts the Sun-Jupiter L1 point, while the comet's outer orbit brushes past the Sun-Jupiter L2. Instead of traveling on the surfaces of orbital tubes, Oterma has been lumbering into them and riding them past the planet.

During these close approaches, the comet performs a Jupiter gravity assist much as the Voyagers did. "Both the comet and the spacecraft took advantage of tubes associated with resonant orbits," Lo says. Each time Oterma


The lunar gateway
1 The telescope leaves its halo orbit around lunar L_1, following an outbound tube.
2 The outbound L_1 tube intersects with an inbound tube to lunar L_2.
Moon
L_1 halo orbit
Earth-Moon L_1
L_2 halo orbit
Earth-Moon L_2
3 This tube takes the telescope out of the lunar gateway region.
Moon's orbit
Sun-Earth L_2
4 The telescope jumps onto an inbound tube leading to a halo orbit around the Sun-Earth L_2 point.
5 At the end of the journey, the telescope glides into a halo orbit around Earth's L_2 point, where it can observe the wider universe.

sweeps through the jovian tubes, the rules of mathematical chaos determine where it ends up next.

Mapping the highway

Lo and his colleagues have shown that mission planners can pick an itinerary for any pair of Lagrange points and a trajectory exists that will follow it. The possibilities have excited a lot of other scientists. Lo's team is now fine-tuning software to develop better maps of the solar system's gravitational currents. Many weird families of orbits have yet to be studied in detail.

"The paths we've looked at previously have been 'free fall' paths, meaning it just takes into account Newton's law of gravity and how planets and moons are moving," Ross says. Mission planners would like to combine the IPS "free ride" with powered flight to get the best of both worlds. For example, a journey could use conventional brute-force thruster power to get to Jupiter's realm relatively quickly, then use the IPS to hop from orbits around different moons. Such a mission already exists on paper.

One IPS application Lo has looked at in detail is building a space station at Earth-Moon L1 to serve as a transportation hub. Any future space telescope would be an ideal commuter. The instrument could be constructed conveniently at nearby lunar L1 and, when complete, shipped via the IPS to Sun-Earth L2.

From there, the telescope would face outward from the Sun and Earth at what is widely seen as astronomy's new mountaintop. Later, if the telescope needed repairs or upgrades, a gentle nudge could send it back through the IPS to the service station at Earth-Moon L1.

Farther ranging destinations are also possible. "The station would also be an excellent staging area for human or robotic missions to the asteroids, Mars, giant planets, and beyond," Ross notes.

Newton's solar system was is a model of cosmic order, Poincaré's is one ruled by chaos. Using insights gleaned from three centuries of studying gravity, the IPS could bring humanity's presence more rapidly, routinely, and completely into space than anyone imagined even a decade ago.

Watch an animation of a space telescope's journey on the IPS, narrated by Martin Lo, at www.Astronomy.com/toc.

The sky this month

Martin Ratcliffe and Alister Ling describe the solar system's changing landscape as it appears in Earth's sky.

November 08

Venus and Jupiter meet again

Brilliant Venus dominated the solar system's second-brightest planet, a still-conspicuous Jupiter (to Venus' upper left), during this conjunction in the summer of 2005. Joe Orman

Jupiter joins Venus at the end of November. The two planets lie just 2° apart after sunset on the 30th. *Astronomy:* Jay Smith

The two brightest planets in the sky, Jupiter and Venus, make a spectacular pair in evening twilight in late November. Once darkness falls, use binoculars to track down Uranus among the background stars of Aquarius.

The chilly early morning hours will be best for viewing Saturn and its narrowing set of rings. During November's first week, you also can catch a fleeting glimpse of Mercury before it heads to a late November conjunction on the Sun's farside.

Without question, **Venus** ranks as the most conspicuous point of light in November's evening sky. It gleams in the southwest after sunset and grows more prominent as it gains altitude during the month. On the North American evening of November 1, a 4-day-old crescent Moon stands 7° to Venus' left. The planet then shines brilliantly at magnitude –4.0. That same evening, **Jupiter** lies 30° to Venus' upper left. The Moon crosses this gap in 2 days, passing less than 3° south of Jupiter November 3.

The gap between Venus and Jupiter narrows about 1° each day. By November's end, the planets lie just 2° (four Moon-widths) apart in the southwestern sky. The constellation Sagittarius serves as an impressive backdrop.

This planet conjunction nearly repeats an event seen in the morning sky this past February. During that conjunction, the two brightest planets stood a single Moon's diameter apart. However, their altitude during this month's conjunction more than doubles that of February.

Such close encounters between Venus and Jupiter happen roughly once a year. However, sometimes the planets lie too close to the Sun for us to see. The next event after this one, on February 16, 2010, occurs only 9° from the Sun. The next decent Venus-Jupiter conjunction occurs before dawn May 11, 2011, but even that can't compete with either of the 2008 events.

Although November's conjunction will look most appealing with the naked eye

— *Continued on page 49*

44 A superb conjunction
49 Meteor watch
49 Rising Moon
50 When to view the planets
50 A jovian eclipse
50 Comet search
51 Locating asteroids
51 Mercury joins Spica

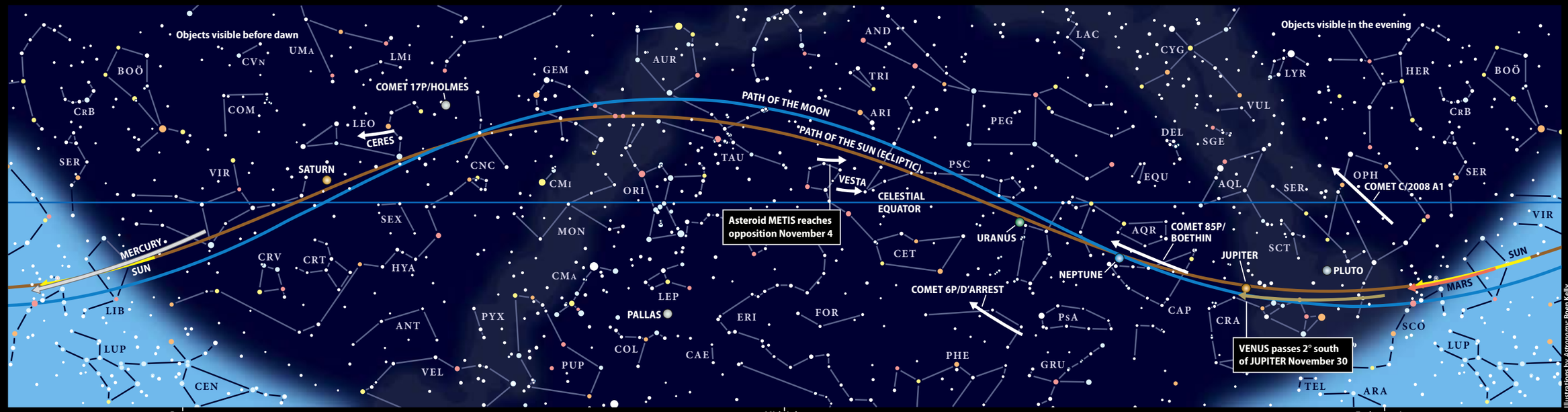
Visible to the naked eye
Visible with binoculars
Visible with a telescope

Planets in November 08

This map unfolds the entire night sky from sunset (at right) until sunrise (at left).
Arrows and colored dots show motions and locations of solar system objects during the month.

Astronomy magazine

Path of the planets



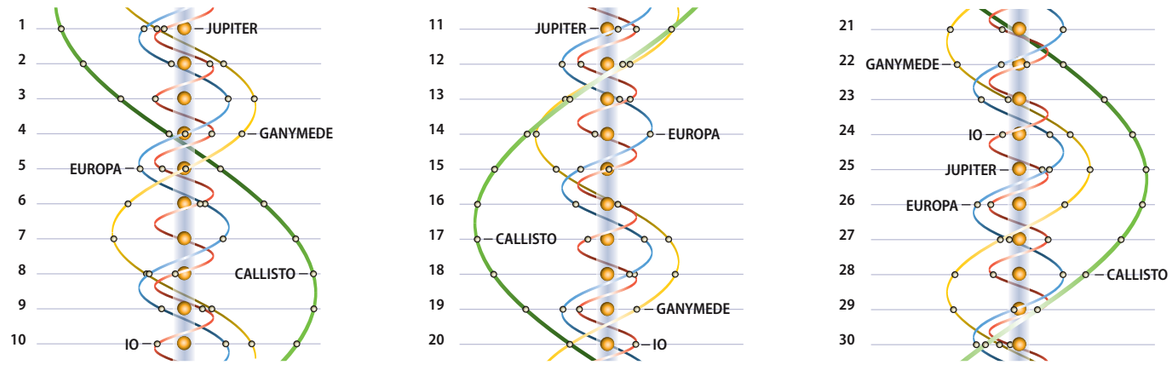
MOON PHASES

To locate the Moon in the sky, draw a line from the phase shown for the day straight up to the curved blue line.
Note: Moons vary in size due to distance from Earth and are shown at 0h Universal Time.

PLANETS	MERCURY	VENUS	MARS	CERES	JUPITER	SATURN	URANUS	NEPTUNE	PLUTO
Date	November 1	November 15	November 15	November 15	November 15	November 15	November 15	November 15	November 15
Magnitude	– 0.9	–4.1	1.4	8.5	– 2.1	1.1	5.8	7.9	14.0
Angular size	5.5"	14.9"	3.7"	0.5"	35.1"	17.0"	3.6"	2.3"	0.1"
Illumination	85%	75%	100%	96%	99%	100%	100%	100%	100%
Distance (AU) from Earth	1.213	1.116	2.498	2.549	5.616	9.758	19.648	30.044	32.337
Distance (AU) from Sun	0.360	0.728	1.518	2.560	5.131	9.354	20.099	30.035	31.553
Right ascension (2000.0)	13h31.9m	18h12.0m	15h46.5m	10h34.1m	9h22.6m	11h25.1m	23h19.6m	21h35.5m	17h57.9m
Declination (2000.0)	–7°31'	–25°34'	– 20°10'	17°54'	– 22°27'	5°46'	– 5°12'	– 14°42'	–17°38'

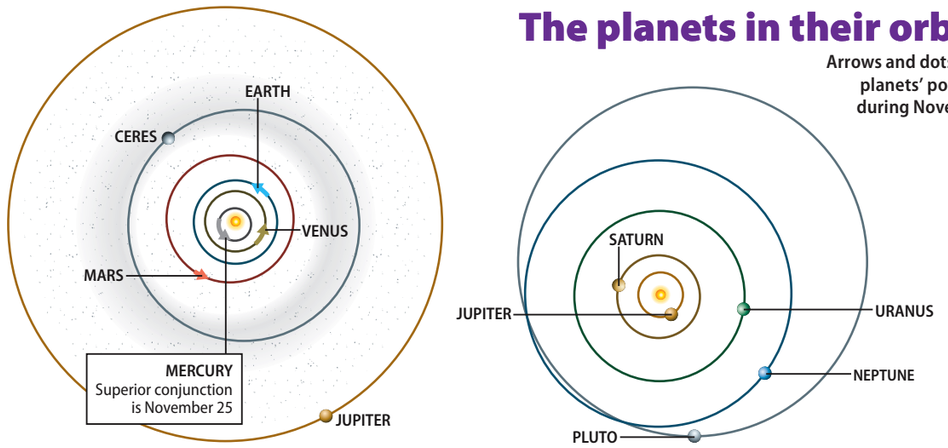
Jupiter's moons

Dots display positions of Galilean satellites at 8 P.M. EST on the date shown.
South is at the top to match the view through a telescope.



The planets in their orbits

Arrows and dots show planets' positions during November.



StarDome

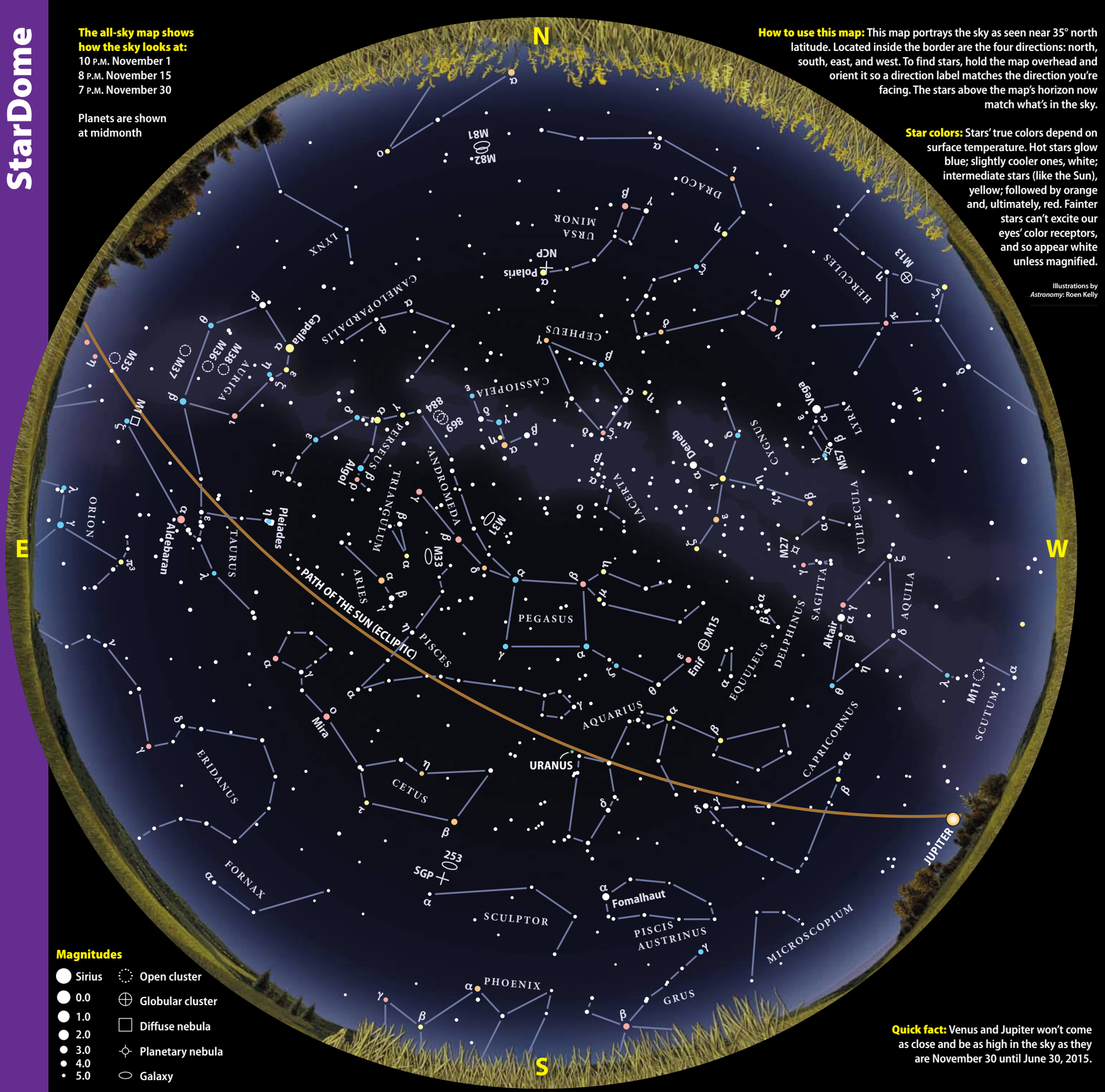
The all-sky map shows how the sky looks at:
10 P.M. November 1
8 P.M. November 15
7 P.M. November 30

Planets are shown at midmonth

How to use this map: This map portrays the sky as seen near 35° north latitude. Located inside the border are the four directions: north, south, east, and west. To find stars, hold the map overhead and orient it so a direction label matches the direction you're facing. The stars above the map's horizon now match what's in the sky.

Star colors: Stars' true colors depend on surface temperature. Hot stars glow blue; slightly cooler ones, white; intermediate stars (like the Sun), yellow; followed by orange and, ultimately, red. Fainter stars can't excite our eyes' color receptors, and so appear white unless magnified.

Illustrations by *Astronomy*: Roen Kelly



Quick fact: Venus and Jupiter won't come as close and be as high in the sky as they are November 30 until June 30, 2015.

November 08

Note: Moon phases in the calendar vary in size due to distance from Earth and are shown at 0h Universal Time.

SUN.	MON.	TUES.	WED.	THURS.	FRI.	SAT.
						1
2	3	4	5	6	7	8
9	10	11	12	13	14	15
16	17	18	19	20	21	22
23	24	25	26	27	28	29
30						

Calendar of events

1 The Moon passes 3° south of Venus, 4 A.M. EDT

2 The Moon is at apogee (252,105 miles from Earth), 12:55 A.M. EDT

3 The Moon passes 1.9° south of Jupiter, 5 P.M. EST

4 Asteroid Metis is at opposition, 2 P.M. EST

5 Southern Taurid meteor shower peaks

First Quarter Moon occurs at 11:03 P.M. EST

6 The Moon passes 1.1° north of Neptune, 2 P.M. EST

8 The Moon passes 4° north of Uranus, 8 P.M. EST

13 Full Moon occurs at 1:17 A.M. EST

14 The Moon is at perigee (223,054 miles from Earth), 5:00 A.M. EST

17 Leonid meteor shower peaks

19 Last Quarter Moon occurs at 4:31 P.M. EST

21 The Moon passes 6° south of Saturn, 1 P.M. EST

25 Mercury is in superior conjunction, noon EST

27 New Moon occurs at 11:55 A.M. EST

29 The Moon is at apogee (252,575 miles from Earth), 11:54 A.M. EST

30 Venus passes 2° south of Jupiter, 8 P.M. EST

Special observing date:

30 Venus and Jupiter appear next to each other in the evening sky.

For definitions of terms, log onto www.Astronomy.com/glossary.

Astronomy magazine

— *Continued from page 44*

or binoculars, both worlds are worth exploring through a telescope all month. On the 1st, Venus displays a disk that spans 14" and appears 78 percent lit. During November, Venus' apparent size grows some 15 percent, reaching 16" across by the 30th. Its disk then appears just over two-thirds illuminated.

Venus shines so brightly that the best telescopic views come during twilight, when its contrast with the background sky is less. Even then, you won't see any detail beyond its size and phase. Thick clouds cover the planet and render it featureless.

Venus lies an average of 26 million miles closer to the Sun than Earth. Consequently, it orbits in less time than we do, rounding the Sun every 225 days. During November, Venus remains behind us on its inner orbital path, but it is catching up. That's why it grows larger in the eyepiece, and we see less of its sunlit hemisphere.

Dramatic phase changes show up only with the inner planets. In general, the outer planets remain essentially "full" from our perspective throughout their orbits. (Mars, the closest outer planet, can display a noticeable gibbous phase.)

If you view Jupiter with the same eyepiece you use on Venus, you'll immediately notice the giant planet's size. Although Jupiter lies more than 5 times farther away than Venus, it appears twice as big. On November 30, Jupiter spans 34".

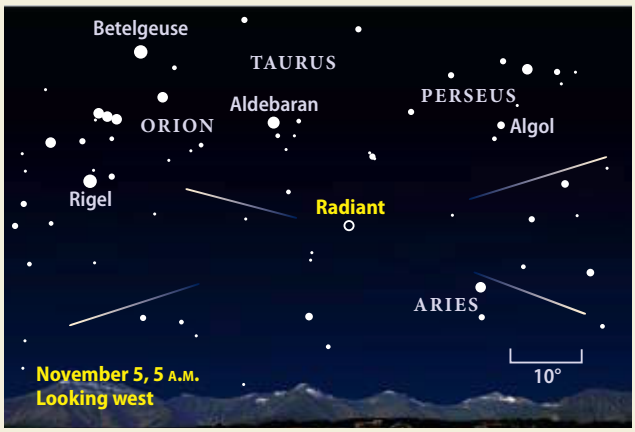
Like Venus, thick clouds envelop Jupiter. But the giant planet's atmosphere displays plenty of features. The most obvious structures are two dark equatorial belts — parallel bands arrayed on either side of a brighter equatorial zone. Under good viewing conditions, you may see a series of dark belts alternating with bright zones.

Unfortunately, Jupiter's altitude in the evening sky decreases this month, so we have to view it through more of Earth's atmosphere. This increases turbulence and diminishes good observing opportunities. The best views will come during twilight, when Jupiter's altitude remains relatively high.

Jupiter reached a configuration known as quadrature in

Martin Ratcliffe *provides professional planetarium development for Sky-Skan Inc.* **Alister Ling** *is a meteorologist for Environment Canada.*

Meteor watch



The Southern Taurid meteor shower may put on a nice show this year, with more activity than usual and lots of bright fireballs. *Astronomy*: Jay Smith

Bullish on the Taurids

A meteor shower takes the name of the constellation from which the meteors radiate. No connection exists between the meteors — tiny bits of comet debris that burn up in Earth's atmosphere — and the stars where the radiant lies. Taurus the Bull claims two November showers. This year, the Southern Taurids have a favorable return — and have the potential for a pleasant surprise.

Both the Northern and Southern Taurids trace their origins to Comet 2P/Encke. Although they usually perform at minor levels, a Southern Taurid "swarm" this year may produce more meteors — and numerous slow-moving fireballs — from late October through November's first week. The young Moon sets before midnight during this period, leaving the favored morning hours free from scattered light. Observers noted increased rates during the three previous predicted outbursts, most recently in 2005.

The Southern Taurid shower peaks November 5. Its radiant lies between the Hyades star cluster in Taurus and the head of Cetus the Whale, and remains visible most of the night.

November's usual top meteor shower — the Leonids — runs afoul of a bright gibbous Moon this year. Although the November 17 peak won't generate lots of meteors, the Leonids often produce bright fireballs. Bottom line: It still pays to keep an eye on the sky around dawn, when the radiant rides high.

Rising Moon

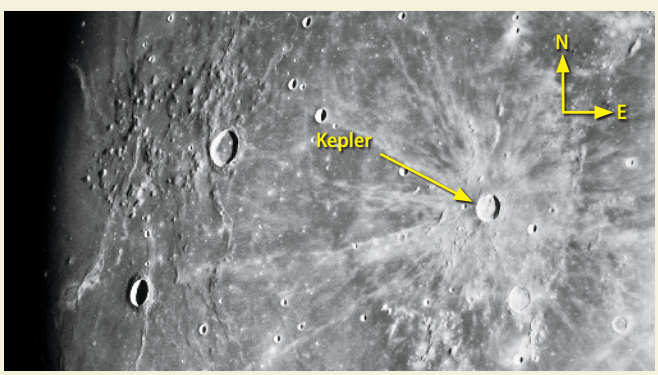
To be young and a crater

There's no hiding the lunar crater Kepler. This 1-billion-year-old impact scar stands out near the Moon's equator, a veritable island in the large basin Oceanus Procellarum, which appears on the Moon's western flank. Sunrise first reveals Kepler November 8.

Kepler is a well-defined circular structure some 20 miles across. Kepler's apparent simplicity is temporary, however. Within a couple of nights, the Sun has climbed in Kepler's sky and gradually hides the relief while simultaneously exposing a bright skirt.

The basin's lava is relatively thin here. This allowed the impact to gouge out lighter-hued rock from below and splatter it about. Several long rays reach across the frozen ocean, adding to the scene.

Over time, the Sun's radiation will darken these rays, but we'll be long gone before that happens. Little has changed here for a billion years. To see a fresher, whiter crater, head north to Aristarchus.



Kepler stands out when the Sun climbs high in the lunar sky, because the relatively recent impact that excavated this crater ejected numerous bright rays. *Consolidated Lunar Atlas*/UA/LPL

When to view **the planets**

EVENING SKY	MIDNIGHT	MORNING SKY
Venus (southwest)	Uranus (west)	Mercury (east)
Jupiter (southwest)		Saturn (southeast)
Uranus (southeast)		

October. At quadrature, the Sun-Earth-Jupiter angle equals 90°, and Jupiter's shadow extends farthest from the planet's disk. Our best views of Jupiter eclipsing its outer moons typically come within a month or two of quadrature.

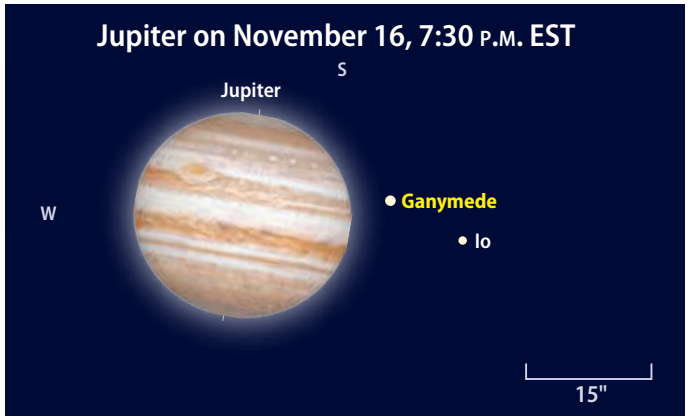
In November, one of the top such events occurs on the 16th. That evening, Ganymede reappears from behind Jupiter's disk and then — less than an hour later —plunges into the planet's shadow. Ganymede pops out from behind Jupiter at 6:49 P.M. EST. Then, at 7:42 P.M. EST, the moon gradually fades from view as it dips into the shadow.

Just before the eclipse gets underway, Ganymede shows up clearly less than 10" east of the planet's limb. The timing for this event favors North Americans east of the Rockies (it remains daylight along the West Coast).

Both Jupiter and Venus appear to gain moons this month when they pass near bright stars. Venus practically grazes 3rd-magnitude Theta (θ) Ophiuchi during the European evening of November 5. By the time night falls in North America, a full Moon-width separates the two.

Venus does it again November 17, in an event well-timed for American observers. Before Venus sets, it passes 5' south of 3rd-magnitude Lambda (λ) Sagittarii, the star marking the lid of Sagittarius' Teapot asterism. Binoculars or a low-power eyepiece on your telescope will provide the best view of this event.

Not to be outdone, Jupiter lies 7' southeast of a 6th-magnitude star November 11. Although the star glows about as bright as the Galilean moons, it clearly lies out of the equatorial plane where the larger jovian moons reside.



Jupiter's satellite, Ganymede, appears for about an hour after sunset November 16, in the short time between when Jupiter occults and eclipses its giant moon. Astronomy: Jay Smith

Head one constellation east of the two brightest planets, and you'll find the faintest planet. Use binoculars to spot **Neptune** in northeastern Capricornus. The 8th-magnitude planet lies 2° north-northwest of 4th-magnitude Gamma (γ) Capricorni.

Neptune's westward (retrograde) motion relative to the background stars comes to a halt in early November. It then begins to move slowly to the east, toward a line of three 5th- to 6th-magnitude stars. A telescope reveals Neptune's 2.3"-diameter disk, which has a subtle blue-gray color.

Uranus lies in Aquarius, one constellation farther east than Neptune. Glowing at magnitude 5.8, Uranus is easy to pick out through binoculars (and can be glimpsed with the naked eye from a dark site). The planet lies about 2° northeast of 4th-magnitude Phi (φ) Aquarii.

Throughout most of November, Uranus makes a beeline toward 96 Aquarii, a possibility that perhaps it was picked up during a mild outburst. If so, there's a chance we could see another.

Comet search

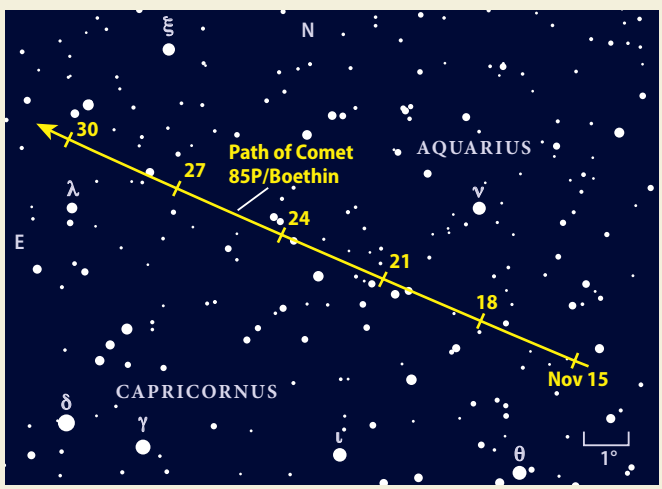
Goodbye McNaught, hello Boethin

Although neither of November's brightest comets belongs to the "flaming" category, it's easy to imagine the celestial torch passing from C/2008 A1 (McNaught) to 85P/Boethin. McNaught's final fling comes November 3, when it glides just 20' from the heart of the bright globular star cluster M10 in central Ophiuchus. You'll need to be observing this pair by 7 P.M. or they'll be too low in the sky.

Once we pass midmonth, the window of Moon-free darkness opens to favor the periodic visitor 85P/Boethin. The geometry for this comet's return is favorable, with Earth lying fairly close to the dirty snowball when it reaches its closest point to the Sun. As a result, we should see it brighten past 8th magnitude as it skims across northern Capricornus.

The comet passes just a few degrees south of the star clusters M72 and M73 in mid-November. Boethin glows a magnitude brighter than the globular cluster M72.

Filipino comet hunter Reverend Leo Boethin discovered this comet in January 1975. Although Jupiter's gravity has been tugging on the comet during the past century, studies of Boethin's nearly 12-year orbit show that the planet can't claim full responsibility for bringing the comet into our view. This leaves us with the intriguing



Comet 85P/Boethin crosses northern Capricornus this month. The best views will come in the evening sky after mid-November. *Astronomy*: Jay Smith

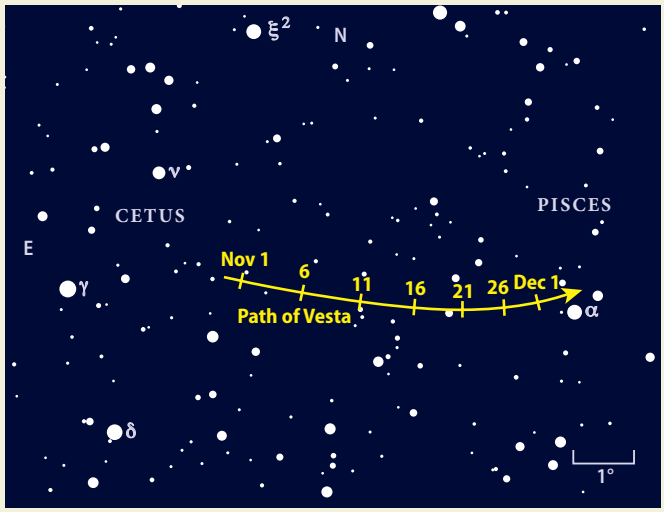
Snare the brightest minor planet

Far from the cover of the Milky Way, asteroid 4 Vesta moves across the open territory of northern Cetus. You can find the Whale rising in the east as night falls. Even without dark adapting, you can grab your binoculars, walk outside, and spy Vesta in just a few minutes.

First, find Cetus' head, a group of a half dozen stars to the right of Taurus. Then, scan west about 5° and you're there. With only a few background stars brighter than 7th-magnitude Vesta, you should be able to find and follow it easily this month, except when the Moon spreads its light across this region from the 9th to the 12th.

Vesta measures some 320 miles across, but it's still mysterious. Scientists eagerly await close-up images, set to be delivered by the Dawn spacecraft in 2011. Still, the Hubble Space Telescope's sharp eye has revealed a massive crater near the asteroid's south pole.

Amazingly, this impact scar spans 80 percent of Vesta's diameter. Why didn't it completely shatter the asteroid? Perhaps results from Dawn will help us to understand. There's a decent chance that some of this blast's debris fell to Earth. Some recovered meteorites have a spectrum remarkably similar to Vesta's.



Asteroid Vesta continues its westward motion during November, heading from northern Cetus into far southeastern Pisces. *Astronomy:* Jay Smith

star marginally brighter than the planet. But Uranus puts on the brakes November 27 when it reaches the end of its retrograde loop, stopping just 6' from the star.

Uranus' motion against the background stars betrays its identity, as does its appearance through a telescope. The planet displays a blue-green disk measuring 3.6" across.

While most of the planets congregate in the evening sky, mornings belong to **Saturn**. The ringed planet lies in southern Leo and rises after midnight all month. A fat crescent Moon passes 6° south of Saturn November 21.

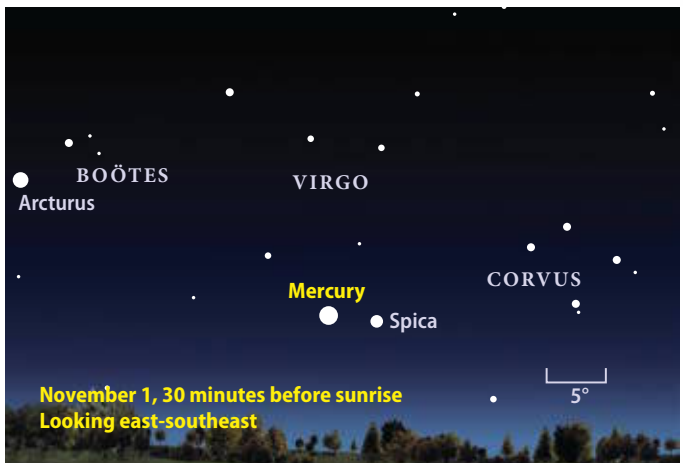
Saturn shines at magnitude 1.1, fainter than it usually does. The reason becomes obvious if you look at the planet through a telescope. The normally glorious rings appear nearly edge-on, rendering them all but invisible and contributing little to the planet's overall brightness.

On November 30, the rings tilt just 1.1° to our line of sight. Their long axis extends a still-healthy 40", but their minor axis measures a paltry 1". We will cross the ring plane in 2009, and the ringed planet will appear anything but for much of the year.

It may be small consolation, but the nearly edge-on rings make this a good time to check out Saturn's disk. The planet's equator spans 17" in mid-November, while the diameter through its poles is 15". Even a small telescope shows this equatorial bulge. It arises because of Saturn's gaseous nature and rapid rotation. The planet spins on its axis once every 10.7 hours.

As the rings approach edge-on and reflect less light in our direction, Saturn's moons will become more prominent. They also will cross in front of and behind the planet, something they don't do at other times. Of all the moons, 8th-magnitude Titan proves easiest to track during a transit. Unfortunately, both Titan transits this month take place before Saturn rises in the Americas.

Iapetus, Saturn's two-faced and far-flung moon, glows at 10th magnitude in early November. It always appears brightest near western elongation, which it reached in late October. As November opens, look for Iapetus some 8' west of Saturn. This moon gets harder to see as the month progresses. By the time it reaches eastern elongation in early December, it will have faded to 12th magnitude.



Mercury shines brightly before dawn during November's first couple of days, just a bit to the left of Virgo's brightest star, Spica. *Astronomy:* Jay Smith

As November arrives, **Mercury** continues its finest morning appearance of 2008. On the 1st, the innermost planet rises 75 minutes before the Sun, offering first-rate views as it stands 4° to the left of Spica in the constellation Virgo. Mercury then shines at magnitude –0.9, some two magnitudes brighter than Virgo's brightest star.

Each morning thereafter, Mercury rises later and in an increasingly brighter sky. By November 9, the planet rises just 50 minutes before sunrise. It will be lost in the solar glare after this date. Mercury passes behind the Sun from our perspective November 25, and will return to the evening sky in December.

Daylight saving time ends in the United States and Canada the morning of November 2, so don't forget to set your clocks back 1 hour.

Inside Earth's magnetic shield

An invisible structure protects Earth from all but the Sun's worst outbursts. Scientists are starting to understand how it works.

by Francis Reddy; illustration by Roen Kelly

A magnetic shield envelops our planet, but the only visible evidence it exists are the rays and curtains of the nightside aurora. Such a structure, which scientists call a magnetosphere, forms wherever the Sun's outflow encounters a strong planetary magnetic field.

In 1958, America's first spacecraft, Explorer 1, began direct study of the magnetosphere when it discovered the Van Allen radiation belts — two regions of charged particles. Since then, scientists have worked to understand the magnetosphere's structure and the complex interactions occurring within it.

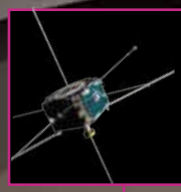
The most recent exploration involves satellite fleets from NASA and the European Space Agency (ESA). NASA's entry is called THEMIS, for Time History of Events and Macroscale Interactions during Substorms. Five probes pursue orbits in which the spacecrafts' highest altitudes periodically align above North American ground stations. In 2007, THEMIS found a temporary hole in Earth's shield. A magnetic conduit called a flux rope formed and decayed over the course of a few hours, channeling solar wind energy inside.

ESA's Cluster mission flies four probes in a pyramid-shaped formation. Findings include giant plasma swirls that form in much the same way as the ripples of a flag in the wind.

Earlier this year, scientists announced that Cluster had located the source of auroral kilometric radiation. The intense 50-to-500-kilohertz radio emission beams into space thousands of miles above auroral regions.

Such broadcasts appear to be common features of all planetary magnetospheres, says Robert Mutel, a Cluster scientist at the University of Iowa. Radio observatories now under construction may one day hear this signal from far-flung alien worlds protected by their own magnetic shields.

Francis Reddy *is a senior editor of* Astronomy.



THEMIS
Launched in 2007, NASA's Time History of Events and Macroscale Interactions during Substorms (THEMIS) mission consists of five identical probes in orbits at different distances.

Bow shock
A shock wave forms as the solar wind encounters Earth's magnetosphere. The oncoming plasma abruptly slows down and heats up.

Earth

Auroral oval
This glowing oval band, which forms around each magnetic pole, is where structured aurorae occur.

Plasmasphere and radiation belts
The plasmasphere contains relatively dense, low-energy plasma. It includes the famous Van Allen radiation belts and can be considered an extension of Earth's ionosphere.

Plasma sheet
This extensive area of low-energy ionized gases in the magnetotail undergoes considerable change during solar storms.

Reconnection
The solar wind magnetic field can briefly merge with Earth's. These so-called reconnection events blast magnetotail plasma toward Earth. THEMIS data proved these events trigger auroral activity cycles (substorms).

Magnetotail
The solar wind stretches the nightside magnetosphere into a tail hundreds of Earth diameters long.

Solar wind
A flow of charged subatomic particles (plasma) streams from the Sun at speeds up to 2 million mph (3 million km/h). It extends the Sun's magnetic field throughout the solar system.

Sun

Magnetosheath
Most of the hot, turbulent plasma behind the bow shock deflects around the space controlled by Earth's magnetic field.

Corona
This is the Sun's outermost atmosphere and the solar wind's source.

Magnetopause
This is the border of Earth's magnetosphere, the boundary that separates the solar wind from plasma within our planet's magnetic control. Under typical conditions, its nose lies 40,000 miles (64,000 km) toward the Sun, but a strong CME can push it closer than geosynchronous orbit.

ACE

SOHO

Coronal mass ejection (CME)
A billion-ton cloud of plasma shot from the Sun, a CME can race through the inner solar system at more than 5 million mph (8 million km/h).

Wind

Early warning system
The NASA/ESA Solar and Heliospheric Observatory (SOHO) and NASA's Advanced Composition Explorer (ACE) and Wind spacecraft monitor solar gusts and gales 930,000 miles (1.5 million km) upwind of Earth.

Flux rope
Solar wind magnetic fields can organize into a short-lived braided bundle that directly channels plasma into the magnetosphere.

Geosynchronous orbit
Satellites 22,240 miles (35,790 km) high complete one orbit each day and remain above a fixed point on Earth. Many weather and communications satellites operate here.

Geotail
This probe, launched in 1992, represents a collaborative effort by NASA and Japan. It explored the magnetotail more than 790,000 miles (1.3 million km) behind Earth.

Cluster
Launched in 2000, four identical probes make up this European Space Agency mission. The probes fly polar orbits but maintain a pyramid-shaped formation.

Hot flow anomaly
A fast stream embedded in the solar wind strikes the bow shock and explodes, creating pressures that briefly push back the magnetopause. THEMIS detected such an event July 4, 2007.

Kelvin-Helmholz vortices
In 2001, Cluster detected swirls of plasma 25,000 miles across (40,000 km) at the magnetopause. The swirls form when fluids move at different speeds across an interface. The same process causes a flag to ripple in the wind.

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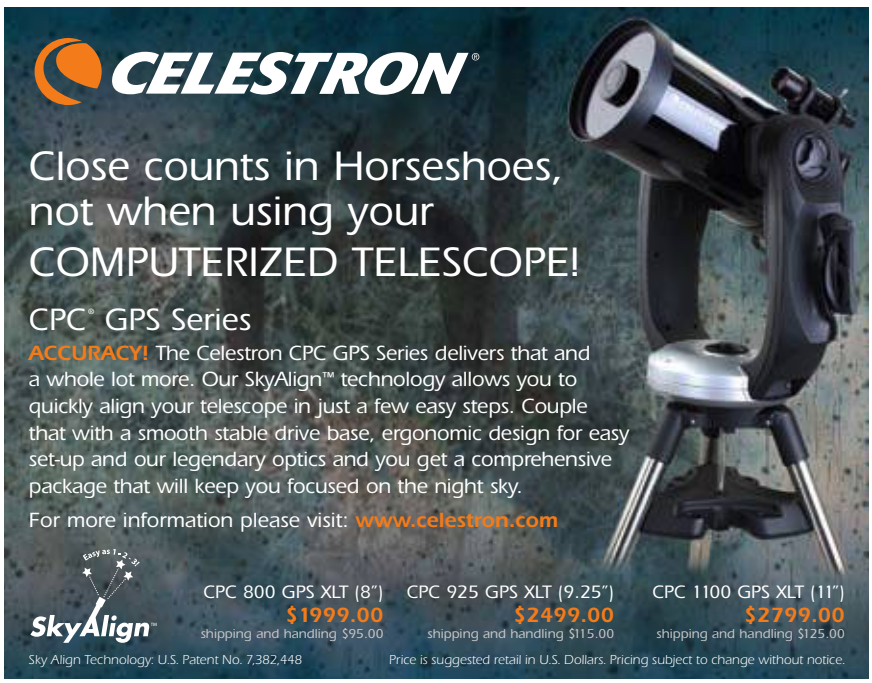
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Why didn't we hear a meteor's sonic boom?

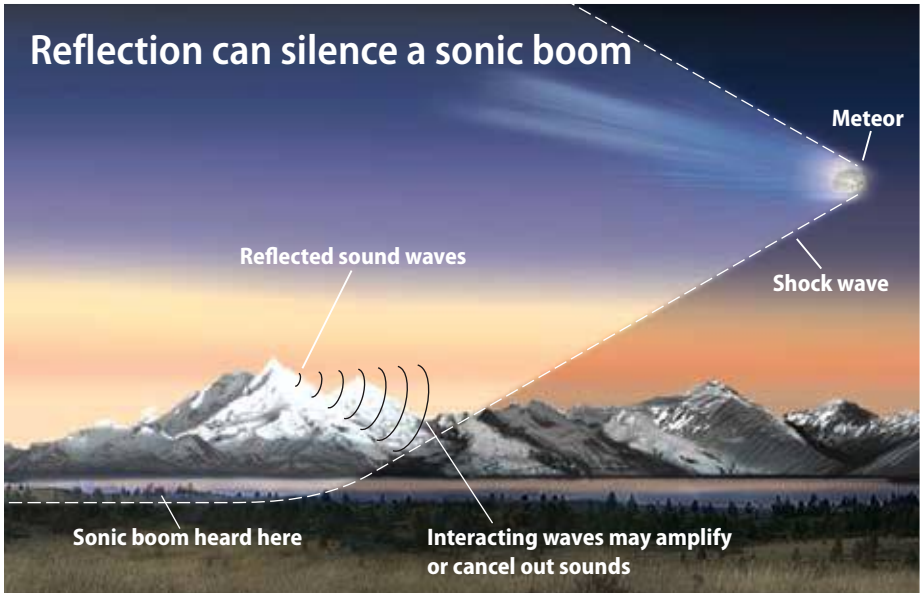
Q: People across town heard a window-rattling sonic boom from the February 19 fireball here, but we heard nothing. Why?

— **Dan Baum,** Pendleton, Oregon

A: Interactions between sound waves can produce regions where the waves are either enhanced or eliminated. Such effects are a major area of study in connection with sonic booms from supersonic aircraft. Wave interactions can lead to amplification so strong a sonic boom can produce damage on the ground, such as broken windows.

Bright meteors produce sonic booms at the ground the same way supersonic aircraft do. A shock wave travels outward from the meteor's path at right angles to its direction of motion. A sonic boom "corridor" exists where the wave sweeps along the ground. In addition, a bright fireball may fragment or detonate (it's then called a bolide). These explosions also can produce sound, but the waves travel in all directions.

In the case of the February 19 fireball, it's likely that the meteor's sonic boom became modified as it interacted with its own reflection from the terrain or ground objects. In some areas, these effects could have amplified the original sound by up to 10 times. Where you live, the waves could have combined in such a way that they exactly canceled out the sonic boom. — **Peter Brown,** University of Western Ontario, London, Ontario


Reflection can silence a sonic boom
Meteor
Reflected sound waves
Shock wave
Sonic boom heard here
Interacting waves may amplify or cancel out sounds

When an object moves through the atmosphere at supersonic speeds, sound waves pile up around it and form a shock wave. A thunderous boom occurs wherever this wave reaches the ground, but terrain like mountains can produce a reflected wave that interferes with it. As a result, some areas may hear a louder sound while others hear nothing. *Astronomy*: Roen Kelly

MERGER MANIA

Q: Why do colliding spiral galaxies make an elliptical galaxy instead of a larger spiral?

— **Kyle H. Wilkins,** Durham, North Carolina

A: When spiral galaxies collide at some angle, their stars get mixed up. The stars that previously followed circular orbits within two relatively thin disks get scattered in all directions and form a puffed-up, roughly football-shaped (elliptical) galaxy.

In contrast, a spiral galaxy starts as a massive, spinning gas cloud. As the gas atoms emit light and cool, the cloud contracts until its spin halts the collapse and forms a thin disk. Eventually, gas clumps within the disk begin to form stars. The new stars lie within the same thin disk in which the gas resided.

The collision of two gas-rich spiral galaxies triggers star formation, which consumes most of the gas quickly. By the time the merger is complete, the merged galaxy lacks sufficient gas to develop into a new spiral. Most of the remaining gas is hot and puffed-up.

Unlike the dense, cool gas clouds that form spiral galaxies, the hot gas in elliptical galaxies can never cool enough to reassemble into a massive galactic disk. Also, the stars in the new elliptical never collide. The elliptical shape of their mixed-up orbits stays the same for the entire age of the universe. — **Abraham Loeb,** Harvard University, Cambridge, Massachusetts

NOT SO FAST

Q: When will the New Horizons spacecraft overtake Voyager 1 as the most distant human-created object in space? — **Robert T. Bluth,** Monterey, California

A: New Horizons will never pass Voyager 1. Voyager 1 received gravity assists from both Jupiter (1979) and Saturn (1980). In 2006, when the probe

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GLOSSARY OF TERMS

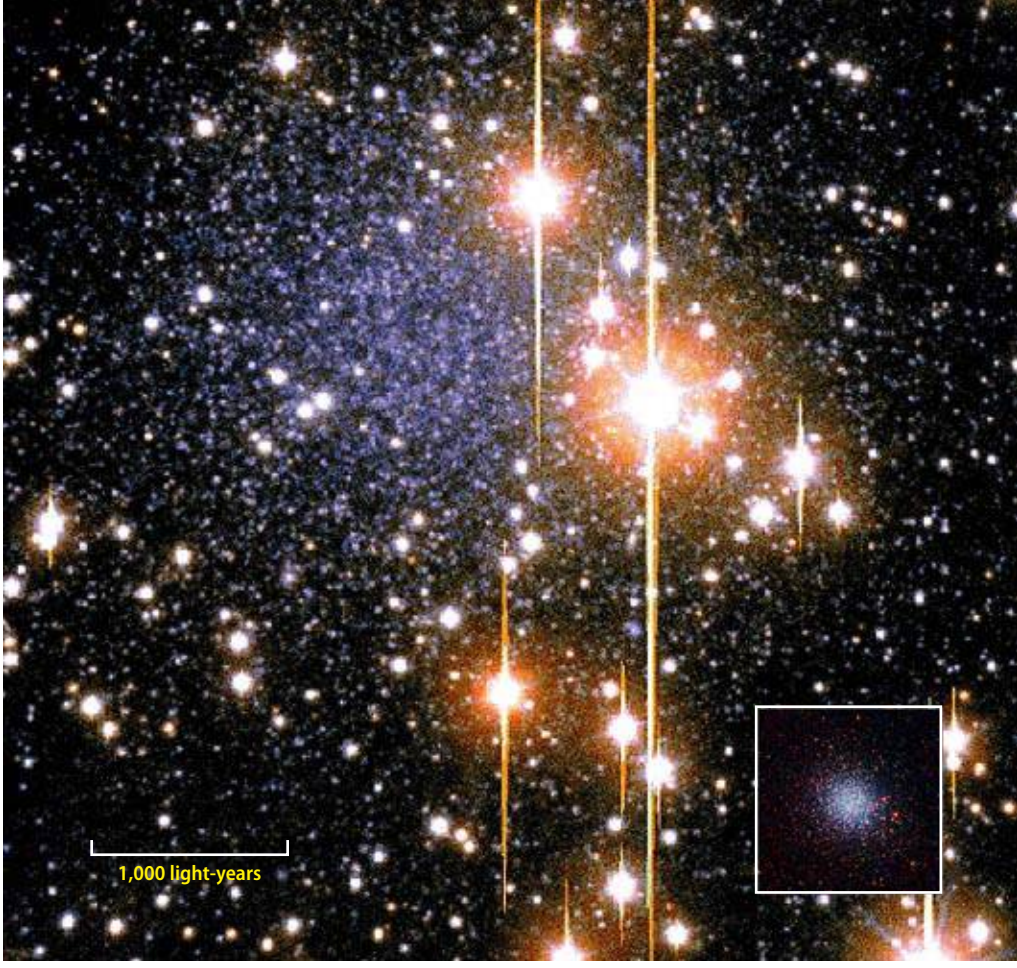
bolide
A meteorite that explodes in Earth's atmosphere.

elliptical galaxy
A galaxy with relatively little gas, random star motions, and an elliptical shape.

dwarf spheroidal galaxy
A low-luminosity, ellipsoid-shaped galaxy more than 650 light-years across.

fireball
A bright meteor with an apparent visual magnitude of –4 or brighter.

globular cluster
A ball of stars less than 200 light-years across that contains no dust or gas and usually orbits a large galaxy.



The Cassiopeia dwarf spheroidal galaxy is a giant compared to Omega Centauri (inset), the Milky Way's largest globular cluster. Globular clusters contain only stars, but dwarf galaxies appear to sport their own dark matter halos. Cassiopeia dwarf: W. M. Keck Observatory; Omega Centauri: NASA/JPL-Caltech/NOAO/AURA/NSF

reached 100 times the average Earth-Sun distance (100 AU), it was leaving the solar system at 38,000 mph (61,000 km/h). New Horizons experienced only a single gravity assist from Jupiter in 2007. When the spacecraft reaches 100 AU in 2038, it will be moving about 29,000 mph (47,000 km/h). — **Michael Buckley,** Johns Hopkins University Applied Physics Laboratory, Laurel, Maryland

GLOBULAR OR GALAXY?

Q: How do you draw the line between a large globular cluster and a dwarf spherical galaxy?
— **Benjamin Birr,** Two Rivers, Wisconsin

A: Size remains the simplest way to distinguish between these two types of objects.

The smallest dwarf spheroidal galaxies we know of measure at least 650 light-years across. In contrast, even the largest globular clusters discovered recently around the Milky Way and our neighbor, the Andromeda Galaxy (M31), are always larger than 200 light-years in diameter.

Also, we see a basic difference between globulars and dwarf spheroidals when we estimate their masses. One way to determine mass is simply by counting all the stars in the system. This turns out to be a good measure in globular clusters, where stars contribute all of the object's mass.

Another way to estimate mass of these objects is by measuring the speed of their fastest-moving stars. The more massive the system, the faster and farther its stars can orbit because there's enough mass to hold onto them. Therefore, the faster the stars move, the higher the total mass of the system.

For globular clusters, both methods give us about the same mass. But for dwarf spheroidal galaxies, the mass obtained from star speeds can be hundreds of times greater than the mass found from star counts. This tells us that globulars and dwarf spheroidals are fundamentally different.

One possible explanation is that dwarf spheroidal galaxies sit within massive dark-matter halos that contribute mass we can detect indirectly from increased star speeds but not see. Globular clusters, in contrast, are just swarms of stars.
— **Vasily Belokurov,** University of Cambridge, England

NO RESPECT

Q: Why doesn't *Astronomy* magazine recognize Messier 110?
— **Keith Lankford,** Harvest, Alabama

A: Amateur astronomers dubbed this object M110 in the 1960s, so we choose not to include it. Charles Messier's list stops at 103 objects. Historically, that should be the last word, but it would be hard to stop there. Imagine excluding the Sombrero Galaxy (M104) from the list! Some sources also include NGC 205, a companion to the Andromeda Galaxy.

Astronomy recognizes 109 Messier objects. The additional six in the list, including M104, were first described in 1783 by French astronomer Pierre Méchain (1744–1804), a contemporary of Messier. — **Michael Bakich,** senior editor

Send your questions via e-mail to: **askastro@astronomy.com**; or write to **Ask Astro, P. O. Box 1612, Waukesha, WI, 53187.** Be sure to tell us your full name and where you live. Unfortunately, we cannot answer all questions submitted.

The northern sky's top 10 galaxies

All you'll need is a dark sky and a small telescope to see these galactic gems. **by Michael E. Bakich**

No celestial objects excite observers more than galaxies. These star cities contain up to a trillion individual suns. Gravity molds them into elegant, ethereal shapes: spiral, elliptical, and irregular.

We see galaxies best in the fall and spring because the Milky Way's gas and dust no longer block them from view. Nineteenth-century astronomers termed the lack of galaxies in the Milky Way's luminous band the "zone of avoidance."

Because you won't find the galaxies on my list in only one part of the sky or during one season, I chose to count down from number 10 to my all-time favorite.

10 The Giraffe's only great galaxy

The first galaxy on the list requires a go-to drive for most amateur astronomers to find it. That's because it lies in the faint, far-northern constellation Camelopardalis the Giraffe. Spiral galaxy NGC 2403 doesn't even have a common name.

Small telescopes show NGC 2403 as an indistinct haze roughly twice as long as it is wide, with a bright central region. Through a 12-inch scope, you'll begin to see its spiral arms, but you'll need an even larger instrument to trace them back to the nucleus.

With most galaxies, using any type of astronomical filter dims the view because galaxies, unlike nebulae, emit lots of light in all wavelengths, and filters pass only a few wavelengths. NGC 2403 shines so brightly that you can break this rule. A nebula filter can help you pick out emission nebulae within its spiral arms.

Spiral galaxy NGC 2403 in Camelopardalis shines at magnitude 8.4. The red patches are glowing hydrogen clouds. You'll need a big scope to trace the arms back to the nucleus. Tony and Daphne Hallas

9 Fireworks in Cepheus

In the 20th century, eight supernovae appeared in the magnificent spiral galaxy NGC 6946, recently dubbed the Fireworks Galaxy.

The Fireworks Galaxy (NGC 6946) in Cepheus is a 9th-magnitude showpiece to astroimagers. Its low surface-brightness, however, tends to frustrate observers. Tony and Daphne Hallas

Bode's Galaxy (M81) lies in the northernmost reaches of Ursa Major. Use an eyepiece that provides a wide field of view to see both M81 and nearby M82. R. Jay GaBany

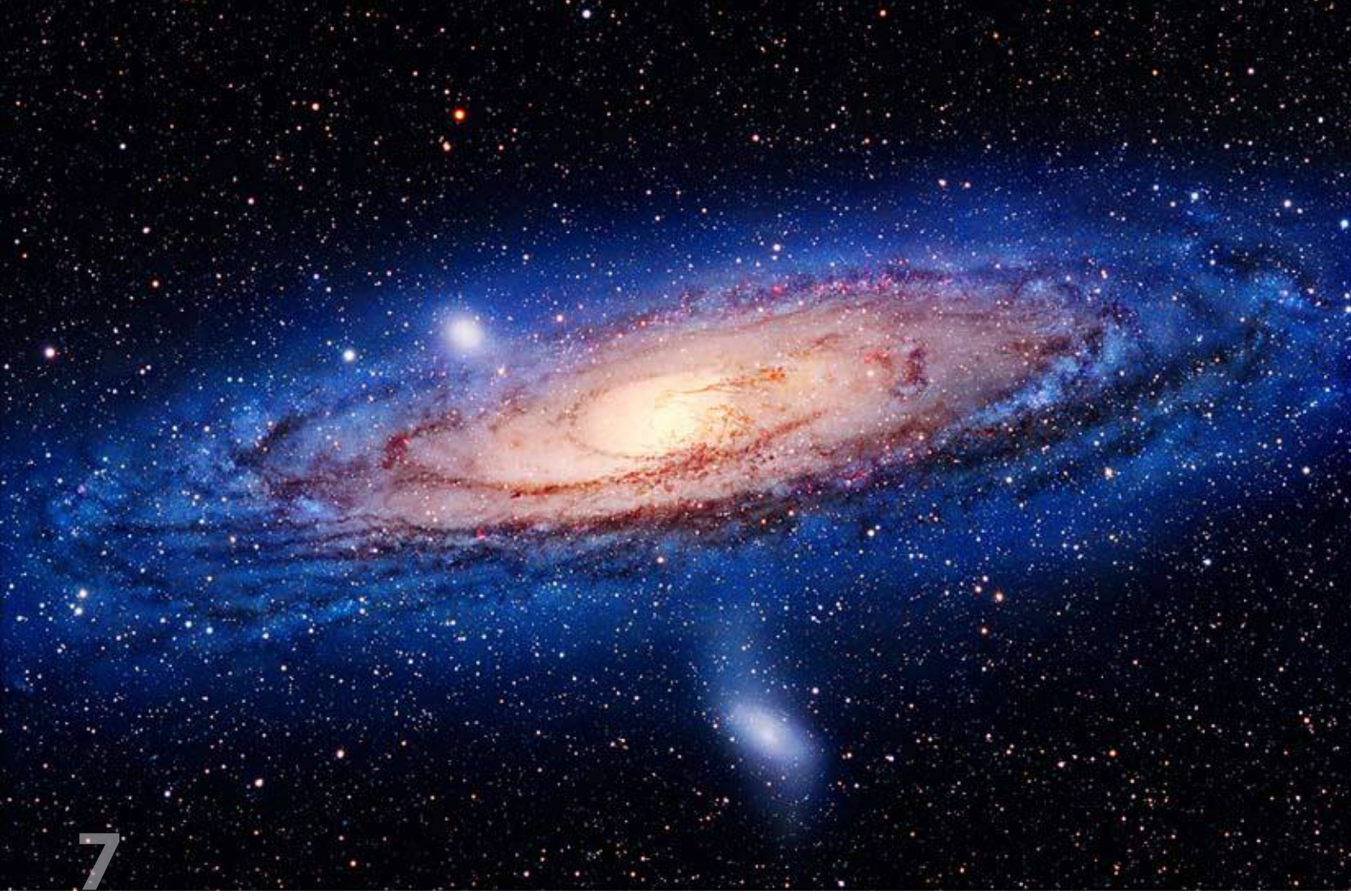
Visually, this galaxy is bright but appears faint. Confused? The galaxy's overall magnitude is a showy 8.9, but it spreads this brightness over a circle 11' across. So, even though it ranks as one of the brightest galaxies, its surface brightness is low. Another hindrance to the Fireworks Galaxy's brightness is its location near the Milky Way.

Although small telescopes will allow you to spot NGC 6946, you won't see much detail with apertures less than about 12 inches. The galaxy's core appears bright. You'll see two arms through a 12-inch scope and four through a 16-inch.

8 A most elegant spiral

Bode's Galaxy (M81) in Ursa Major presents a bright oval through small telescopes or binoculars. Closer observation

Michael E. Bakich *is a senior editor of* Astronomy. *He loves observing galaxies in the spring and fall.*



The Andromeda Galaxy (M31) is the galaxy many observers rate as the Northern Hemisphere's finest. Whatever size telescope you use, this object will reward the time you spend observing it. Tony and Daphne Hallas

through larger instruments reveals this spiral's tightly wound arms.

Through an 8-inch telescope, you'll see a large, bright central region surrounding the galaxy's much brighter core. Larger scopes will let you see the spiral arms. Note that the easternmost arm is easier to see.

Top 10 northern galaxies

Name	R. A. (2000.0)	Dec.	Mag.	Size
NGC 2403	7h37m	65°36'	8.4	18' by 11'
NGC 6946	20h35m	60°09'	8.9	11'
M81	9h56m	69°04'	6.9	21' by 10'
M31	0h43m	41°16'	3.4	180' by 65'
M63	13h16m	42°02'	8.6	10' by 6'
NGC 4565	12h36m	25°59'	9.6	16' by 3'
M51	13h30m	47°12'	8.4	11' by 7'
M101	14h03m	54°21'	7.9	22'
NGC 4631	12h42m	32°32'	9.8	17' by 4'
M82	9h56m	69°41'	8.4	9' by 4'

R. A. = Right ascension; Dec. = Declination; Mag. = Magnitude

7 The Great Galaxy

Many observers rank the Andromeda Galaxy (M31) as the ultimate northern deep-sky object. From a dark site, you'll see it with your naked eyes as a hazy patch of light that looks like a small, detached piece of the Milky Way. Find it 1° west of Nu (ν) Andromedae.

The Andromeda Galaxy is a showpiece through any telescope. Small scopes with eyepieces that give a wide field of view allow you to study the galaxy's overall structure. Can you see the dark dust lane that defines M31's western edge? Move up to a 6-inch scope at a dark site, and you'll see two dust lanes.

M31's two companions, M32 and NGC 205, are small elliptical galaxies. Such objects normally appear featureless, and these two have another disadvantage: their close proximity to bright M31.

6 In the sky garden

The Sunflower Galaxy (M63) in Canes Venatici may remind you of summer fields, but only if your telescope is large enough. Although the name "Sunflower Galaxy" might imply a face-on view, M63 tips 60° to our line of sight.

Through small telescopes, M63's nucleus appears stellar, and a 3'-long oval halo surrounds it. Outside the nucleus, the arms fade with increasing distance. Through even large amateur telescopes,

The Sunflower Galaxy (M63) in Canes Venatici contains details a small telescope won't reveal. For the best views of this magnitude 8.6 object — especially of the galaxy's spiral structure — use a 10-inch or larger scope. Bob and Janice Fera

The Needle Galaxy (NGC 4565) in Coma Berenices is 10' long and has a small central bulge only 1.5' thick. The dust lane running its length is easiest to see against the bright central region. Bruce Hugo and Leslie Gaul/Adam Block/NOAO/AURA/NSF

you'll see only hints of the many spiral arms that radiate outward.

5 Needle in a cosmic haystack

I've heard audible gasps from observers scanning the deep sky in Coma Berenices when they come across the Needle Galaxy (NGC 4565). I'm not alone when I rate this object as the sky's finest edge-on spiral galaxy.

Through an 8-inch scope, you'll detect a sliver of light 10' long and only 1.5' thick oriented northwest to southeast. As you increase the size of your telescope, the apparent length of the Needle Galaxy also increases. A 16-inch scope reveals the galaxy's full extent of 16'.

A dust lane runs the entire length of this object, masking much of the arms' brightness. The central region features a small bulge, which is the easiest place to detect the dust lane.

4 Lord Rosse's spiral

The Whirlpool Galaxy (M51) in Canes Venatici is such a magnificent face-on spiral that some stargazers have spent entire nights observing it. Yes, I was one of them.

The Whirlpool Galaxy (M51) in Canes Venatici lies one-quarter of the way between Alkaid (Eta [η] Ursae Majoris) and Cor Caroli (Alpha [α] Canum Venaticorum). Through a large scope, look for the edge-on spiral IC 4277 to the lower left of NGC 5195. Tony and Daphne Hallas

You'll see M51's spiral arms through 8-inch or larger telescopes. Through a 12-inch scope, they appear patchy and reveal much greater detail. Look for the thin, dark dust lanes that follow the arms' inner edges. Also, try to spot the apparent connecting arm between M51 and its companion, NGC 5195. Although M51 is larger, NGC 5195's core appears brighter.

3 Big and beautiful

To observe my third-favorite galaxy, M101, you'll want to use a 10-inch or larger telescope to counteract its low

Spiral galaxy M101 in Ursa Major spins through space like a cosmic propeller. Use a 10-inch or larger scope for detailed observing because M101 has a low surface brightness. Tony and Daphne Hallas

surface-brightness. Smaller instruments will show the galaxy's bright core, but you'll need a large scope and a dark site to spot M101's multiple spiral arms.

M101's core is concentrated but doesn't appear starlike. Many huge, young star clusters called stellar associations and star-forming regions lie along its spiral arms. These objects are so bright, astronomers have assigned seven of them their own NGC numbers.

2 A whale of a galaxy

Observe the Whale Galaxy (NGC 4631) through a 12-inch or larger telescope, and you'll understand how it got that name. Observers have commented that NGC 4631 doesn't look like an edge-on spiral. Yet this object is one of the sky's brightest edge-on galaxies.

Large telescopes will reveal NGC 4631's smaller companion — dwarf spheroidal galaxy NGC 4627, which sits 2.5' northwest. NGC 4627's gravity has distorted the Whale's spiral structure. Through the largest amateur telescopes, you may see the bridge of material connecting the two galaxies.

The Whale Galaxy (NGC 4631) in Canes Venatici travels through space with a small companion, dwarf spheroidal galaxy NGC 4627. John Vickery and Jim Matthes/Adam Block/NOAO/AURA/NSF

1 Bursting with stars

Despite it being my favorite northern galaxy, M82 has a rather weak common name: the Cigar Galaxy. Astronomers have placed it in a classification that tells the real story. M82 is a starburst galaxy. Massive amounts of star formation dominate this object's structure.

Through the eyepiece, M82 appears 4 times as long as it does wide, and its long axis orients east-southeast to west-northwest. The galaxy's brightest part lies east of its center. Farther east, a dark lane cuts diagonally across M82's minor axis.

M82 has high surface brightness. To illustrate what this means, compare M82 to M81 (0.6° due north) in an eyepiece that just frames both. Although M82 shines a magnitude and a half fainter than M81, it appears about as bright.

To the hunt

The galaxies on this list are not difficult to observe. All you need is a high-quality 6-inch or larger telescope and access to a dark sky. Change eyepieces frequently. That will allow you to view at different magnifications, and each change should show different details.

The Cigar Galaxy (M82) in Ursa Major is a starburst galaxy. A high rate of star formation occurs in such objects. Tony and Daphne Hallas

If you're a budding amateur astronomer interested in observing galaxies, my top 10 is a great starter course. More experienced observers can look at this list as a refresher. If you're like me, you mainly show the brightest galaxies to others, concentrating your personal telescope time for more elusive prey. Revisiting these showpieces on your own from time to time will revive your "wow" response. After all, objects like these got us into astronomy in the first place.

I'd love to know your northern top 10 galaxies. E-mail them to me at mbakich@astronomy.com. Add as much or as little as you like about why they're your favorites. I'll blog about the results on *Astronomy.com* in a month or so.

Top 10 southern galaxies

Name	R. A. (2000.0)	Dec.	Mag.	Size
NGC 253	0h48m	–25°17'	7.1	25' by 7'
SMC	0h53m	–72°50'	2.3	5°20' by 3°05'
NGC 300	0h55m	–37°41'	8.1	20' by 13'
NGC 1365	3h34m	–36°08'	9.5	11' by 6.2'
LMC	5h24m	–69°45'	0.1	10° by 9°
M104	12h40m	–11°37'	8.0	9' by 4'
M83	13h37m	–29°52'	7.5	11'
NGC 5128	13h26m	–43°01'	7.0	18'
NGC 6744	19h10m	–63°51'	9.1	20' by 13'
NGC 6822	19h45m	–14°48'	9.3	16' by 14'

R. A. = Right ascension; Dec. = Declination; Mag. = Magnitude

Scandinavian sky show

Where the northern lights dance

In Tromsø, Norway, pristine fjords and rugged mountains frame some of the greatest auroral shows on Earth.
text and photos by Hinrich Bäsemann

Above the arctic coast of Norway, a green sea of light is glowing. Fluorescent lights dance up and down, folding into gauzelike curtains. Then, reddish cascades of light flash like lightning over the silent landscape.

These are only a few manifestations of the aurora borealis, or northern lights. Anyone who sees an aurora for the first time is utterly spellbound. It is surely one of the most beautiful phenomena in nature.

In the Middle Ages, people saw the northern lights as harbingers of unhappy events, such as the death of a king, war, famine, or natural catastrophes. In modern times, we think of ourselves as above such superstitious beliefs.

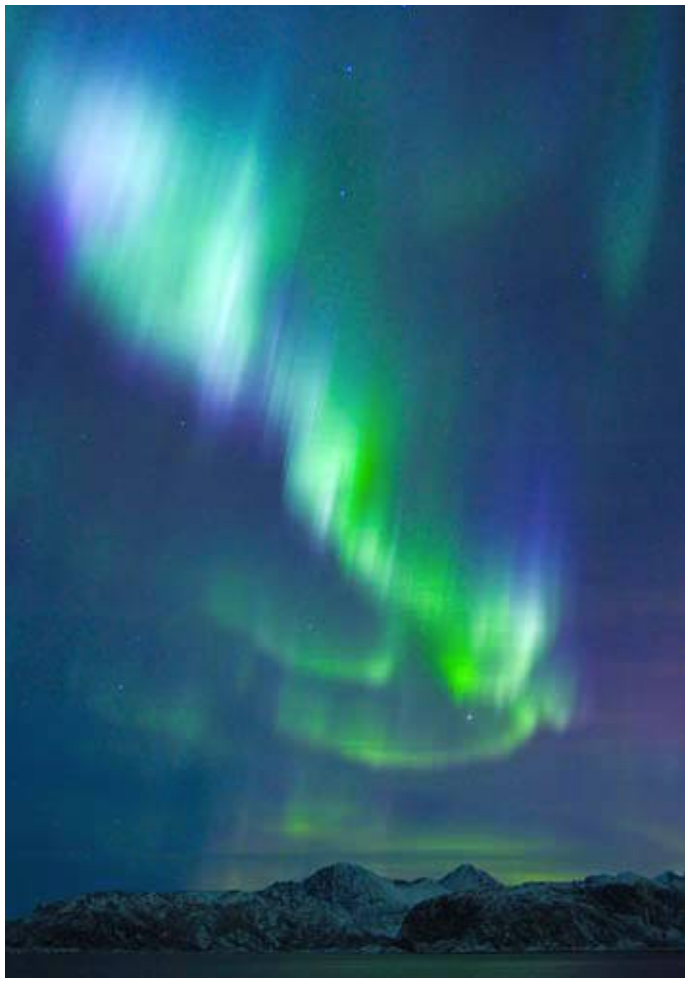
Times change — or maybe they don't after all. On September 11, 2001, as terrorists attacked the World Trade Center and the Pentagon in the United States, we in Tromsø witnessed one of the most spectacular auroral displays in years. In the clear fall night, gleaming green, yellow, and red beams shot across the firmament. This miraculous natural spectacle helped us to cope with the horrendous events of the day.

Hinrich Bäsemann *is a writer and photographer who divides his time between Tromsø, Norway, and Hamburg, Germany.*

Electric Sun

The northern lights exist because of our restless Sun and Earth's magnetic field. In addition to light, the Sun emits a wavering

Writers and photographer Hinrich Bäsemann shoots the aurora from Tromsø's western shore. Across the water, the town of Kvaløysletta illuminates the night.



A billowing curtain of aurora exhibits a dazzling range of color and brightness over the mountainous Tromsø region.

The Tromsø Kommune comprises all or portions of islands along the Norwegian Sea. The region lies within the Arctic Circle, and people have lived there since the end of the Ice Age. Tromsø, the kommune's capital city, hosts the world's northernmost university.

current of charged particles — mainly electrons and protons. They form the solar wind, which sweeps through the planetary system at speeds up to 2.2 million mph (3.5 million km/h).

Particles collide with atoms and molecules in Earth's atmosphere. The strongest interactions occur at altitudes of 50 to 200 miles (80 to 320 kilometers), and each generates a tiny amount of light. The result of myriad collisions is a weak glimmer — the northern lights — that enlivens the solitude of the polar night with their pastel colors and fantastic shapes.

Yellow and green dominate most aurorae, although red also appears. The colors give us an indication of which air molecules (oxygen or nitrogen) interacted with the solar wind, and at what altitude. Oxygen molecules at an altitude of about

Luminous auroral curtains shimmer over Håja, a small, uninhabited island (left center) with a distinctively pointy peak. The island lies off the west coast of Kvaløya.

60 miles (100 km) produce yellow and green light. But at higher altitudes of around 200 miles (320 km), the same oxygen molecules emit red light. In contrast, electrically charged nitrogen (ions) produces red light, while neutral nitrogen molecules glow red-purple.

The aurora in history

People wondered about the nature of the aurora centuries before scientists unlocked its scientific secrets. The Norwegian polar explorer and Nobel laureate Fridtjof Nansen wrote one of the most beautiful historical descriptions of the northern lights during his 1893–1896 journey to the North Pole in the exploration vessel Fram.

Nansen recalled the unforgettable moment when he stepped on deck and observed the aurora. "Seldom or never have I seen such shining colors," Nansen wrote. "The predominant color was at first yellow, which however gradually glimmered into green, whereupon at the lower end of the rays on the lower side of the arc a sparkling ruby-red appeared which soon spread across the entire arc."

Many centuries before Nansen's time, the Vikings had already coined the term "northern lights." A famous instruction

^ A dramatic red aurora lights the sky above the Malangen Peninsula.

> A bright green curtain of aurora erupts from the dark sky over Tromsø.

< A brilliant blue starburst announces the auroral corona (near left), in which rays of light appear to converge at a point.

<< A fisheye-lens portrait (far left) captures auroral curtains billowing above the Moon. The bridge at left leads to the small island Sommarøy, a holiday resort on the Tromsø region's ocean coast.

book to the Viking monarch written in about 1250, *The King's Mirror*, used the word *nordurljos* (northern lights) for the first time. The book says, "When these rays are at their highest and brightest, then there is so much light that you can see your way outside, or even go hunting."

Ghosts in the sky

In those days, says northern lights researcher Asgeir Brekke of Tromsø University, the aurora was a "beautiful, sparkling signpost to Greenland" for the Vikings. The poets who wrote the historical sagas and mythologies of Scandinavia also drew inspiration from the northern lights. For example, auroral displays might have inspired the mythical rainbow bridge Bifrost that links Asgard — the home of the gods in Norse mythology — to the realm of mortals.

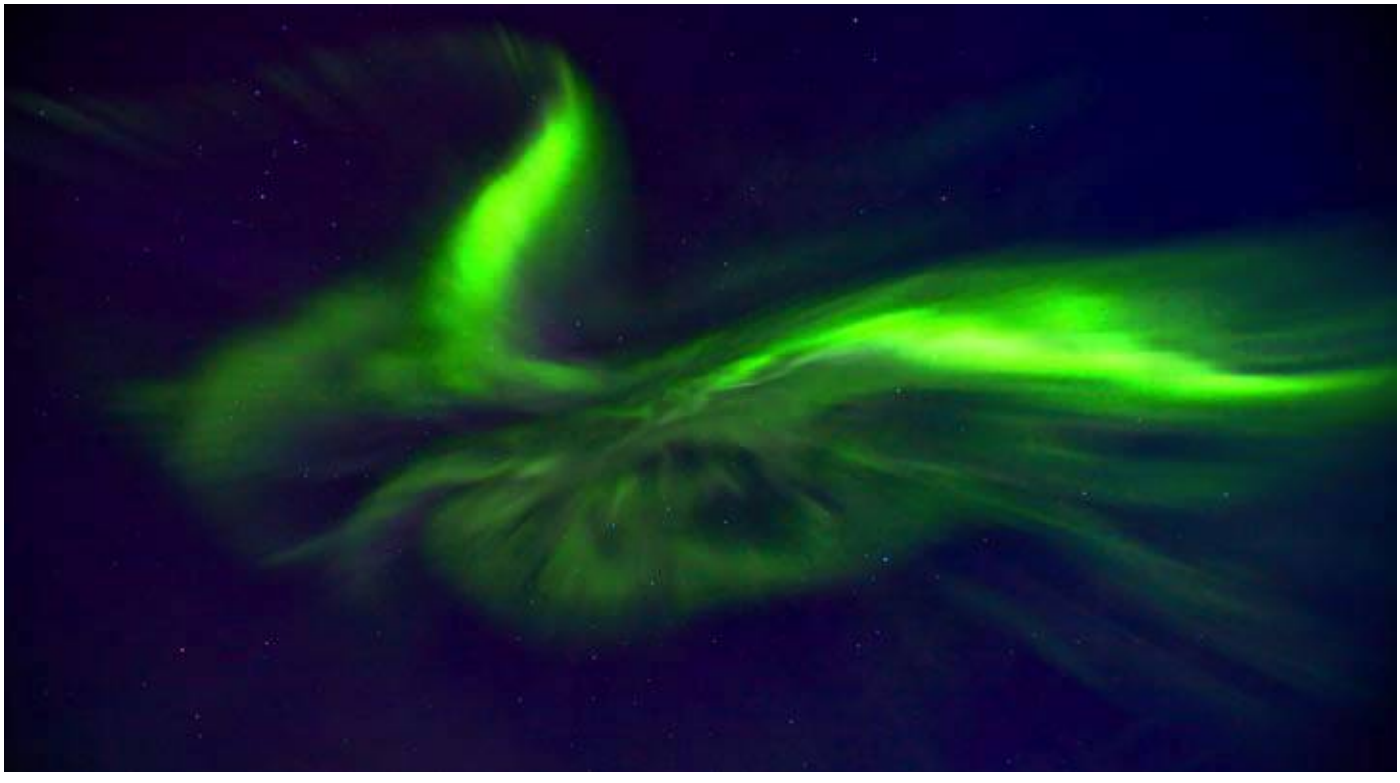
Bifrost was also a link between life and death. When the arcs of auroral light burst, it was seen as a warning that the bridge would break up at Ragnarok, the apocalyptic final battle between the Norse gods.

The northern lights also may have a connection to the Valkyries, female deities in Norse mythology. They serve Odin, the father of gods, decked out in sparkling armor. The aurora may have evoked the ghostly image of the shield-bearing Valkyries marching across the sky.

The aurora appears frequently in the cultures of Scandinavia. Greenlanders recognize the souls of their dead in the auroral glow. In the eyes of numerous Norwegian coastal fishermen, the heavenly fire resembles the glimmering of a moving shoal of herrings. In the nocturnal lights, Finnish hunters imagine the whipping tail of the polar fox in the soft snow of Lappland.

The aurora beams over Hillesøy Church on Kvaløya. Historians speculate that similar displays might have inspired Bifrost, the mythical rainbow bridge to Asgard, home of the Norse gods.

Electrically charged particles from the Sun whiz into the atmosphere, following Earth's magnetic field. Collisions with oxygen and nitrogen produce the auroral lights, like this spiky display over Tromsø September 11, 2001.



In other ways, the northern lights inspire the imagination. People frequently report hearing sounds with the aurora, often described as a fine tinkling, or perhaps murmurs and moaning sounds. Inhabitants of the Shetland Islands, Siberian natives, the Inuit (Eskimos), and Sámi people all report auroral sounds.

Perhaps it is simply that whoever sees the northern lights instinctively listens for some sort of soundtrack, for such a grand display seems unthinkable without thundering noise to accompany it. But in reality, a supernatural silence governs, although perhaps a touch of wind moans in the empty branches of a birch tree, or the snow crystals rustle softly nearby.

Freeze frame

The aurora appears throughout the year, in summer as well as in winter. Satellite images confirm this. But in Tromsø, the nights get dark enough to recognize the northern lights only after the end of August. The season ends in early April.

In the arctic winter, when I photograph the aurora, proper clothing is as essential as a camera. The night can become brutally cold, especially inland. Heavily insulated boots are a must. Dressing the body follows the onion principle, with multiple layers of clothing to fight off the cold. The outermost layer must be absolutely windproof.

^ Yellow and blue auroral arcs fan across the sunset. The Norwegian Sea lies beyond this mountain-fringed body of water, the Ersfjord.

< Bizarre shapes, like this auroral creature reminiscent of a bird with outstretched wings, suddenly erupt in the sky during auroral displays. Often the sky seems to come alive.

The body parts particularly vulnerable to arctic conditions are the hands and ears. To catch the best displays, one must sometimes wait for hours, hardly moving. A heavy fur cap with flaps takes care of the ears. Thick mittens protect the hands.

But when the heavenly drama starts, it is time to shed the mittens for another type of protective gear: gloves that expose the thumb and index finger to operate the camera. But one must be careful. In the excitement, it's easy to forget about the bitter cold. In a very short time, the fingers become so stiff that it's difficult to change batteries, film, or memory cards.

Small and inconspicuous as they may be, batteries are the linchpin of arctic auroral photography. Without them nothing works, and in the cold they lose their power in no time. I carry spare batteries, memory cards, and rolls of film close to my body, where the warmth keeps everything working.

My film cameras have worked quite well in arctic conditions, even at temperatures below –4° Fahrenheit (–20° Celsius). If you shoot with a digital camera, the arctic chill can even be an advantage. In warmer environments, the imaging chip in digital cameras adds random electronic "noise" to your image. But in frosty temperatures, the noise diminishes substantially.

An intense green and violet aurora glows in the sky above the Skittentinden Mountains on Kvaløya.

In the excitement of photographing a heavenly display, I avoid breathing on the viewfinder or lens! This would immediately coat them with opaque frost, cutting off my view of the action. And as you excitedly work the shutter, don't forget to step back once in a while and enjoy the beauty and grandeur of the greatest sky show on Earth.

To see more of the author's auroral photographs, go to the web extra gallery at www.Astronomy.com/toc.

How to shoot stars with a webcam

Adhara (Epsilon Canis Majoris)

A small, inexpensive video camera offers surprisingly good results when imaging stars.
text and images by Fred Ringwald

The Philips ToUcam Pro II 840K webcam (left) is the camera the author used to take all of the other images in this article. At right is a newer Philips SPC900NC. It contains an adapter, supplied by Adirondack Video Astronomy, which fits a 1¼" eyepiece holder.

Webcams have revolutionized planetary, lunar, and solar imaging. Primarily developed for exchanging video over the Internet, these small, digital video cameras came into wide use in astronomy during the 2003 opposition of Mars. Their advantage lies in the number of short-exposure images they capture.

As a photographer shoots a series of images at five to 30 frames per second, the webcam records the object and the turbulent motion of Earth's atmosphere. This turbulence, called "seeing," blurs images. Software can search a video and select the best frames. It then sums them into one image that's almost as clear as if the atmosphere weren't there. Free software to do this, called *Registax*, is available at: www.astronomie.be/registax/.

Fred Ringwald *is an associate professor in the Department of Physics at California State University, Fresno.*

A simple process

The camera that took the images shown here is a Philips ToUcam (pronounced "to-YOU-cam") Pro II 840K. This model was popular several years ago but is no longer made, having been replaced by the Philips SPC900NC. This camera costs only about $150, and is available from many vendors. These vendors also supply adapters, so a webcam can fit into the tube for a 1¼" eyepiece.

To use a webcam, you need a computer with a USB port (although some cameras now use a FireWire connection). Webcams don't need to be cooled or calibrated, although this can improve the finished image's quality.

You can even get by with a telescope mount that doesn't track well. The Moon and planets (except for Uranus and Neptune) are bright, so long exposures (greater than 1 second) aren't needed.

At Fresno State University, I teach observational astronomy. The students are mostly physics majors but few have

Gamma Geminorum

Capella (Alpha Aurigae)

Herschel's Garnet Star (Mu Cephei)

Fomalhaut (Alpha Piscis Austrinus)

^ Most of the images the author produces capture a region of sky measuring 21" square. Some wide double-star images may need a box 42" on a side. Keeping his star images to the same scale allows quick comparisons between the separations of stellar pairs.

used a telescope. This is why I still like the ToUcam. It's easier to operate than the other CCD cameras used later in the course because it produces color images right out of the camera. With the other CCD cameras, you have to combine three filtered exposures.

My students need to learn the prominent constellations, which readers of this magazine know is important. Our telescope has a go-to mount, but we have to calibrate it each night by pointing it at known bright stars.

To teach how to point and focus a telescope, as well as the techniques of introductory imaging, I encourage students to use the ToUcam to take pictures of individual bright stars. The Moon and bright planets also work, but they aren't always visible.

Star-shooting details

When imaging stars with the ToUcam, I normally use a 2x Barlow lens. When used with our 16-inch Meade LX200 telescope, this accessory produces an image scale of 0.142" per pixel at f/20.

I cropped the images into 150x150-pixel thumbnail images to fit as many as possible onto my Web page. The star-image frames shown here measure 21 arcseconds (") across. Some, such as 61 Cygni, are 43" across.

I think the thumbnails look better when compared side by side. You can't help but notice the stars' colors and companions. The colors the ToUcam sees aren't exactly what most human eyes see. Notice the green stars, such as Adhara. The eye usually doesn't perceive stars as green. Rather, it sees them as white because the eye's response to light spans a narrower range of wavelengths than the stars radiate.

If stars do appear green, it's usually because of refraction caused by Earth's atmosphere (when the star lies low in the

Mizar and Alcor (Zeta [ζ] and 80 Ursae Majoris) presented a vision test for Roman soldiers 2,000 years ago. Today, amateur astronomers know them as the pair of stars in the bend of the Big Dipper's handle.

V Double stars like the three shown below are fun to observe because no two pairs look alike. Sometimes, because of a contrast effect, a bright reddish star will trick your eyes into seeing its fainter companion star as green. This is the case with Ras Algethi (Alpha Herculis).

Gamma Delphini

61 Cygni

Ras Algethi (Alpha Herculis)

Almach
(Gamma Andromedae)

Cor Caroli
(Alpha Canum Venaticorum)

Graffias (Beta Scorpii)

Zeta Cancri

^ Colorful double stars are a joy to observe or image. It does take some time at the telescope to train your eyes to see color, but the payoff is a big one. When you image such stars, however, you'll see quickly how much better than your eyes the camera is at recording color.

sky). Alternately, it could be a contrast effect caused by a bright red companion in a double star system.

I usually shoot between 1,000 and 2,000 frames per video and save the file in an .avi format. The processing for stars is among the easiest possible, and it works well as an introduction to *Registax*. Just select the video to process, click on the star to put an alignment box around it, select "Automatic processing," and let *Registax* rip by clicking the "Align" button. *Registax* will automatically align, optimize, and stack the images.

When shooting stars, I don't bother with wavelet processing or other fancy methods that can improve planetary images. I usually use the "Gradient quality estimator," with the "Lowest quality" box set to 80 percent or higher because the observatory is near sea level. This setting usually selects only the best 5 to 10 percent of the frames.

Sometimes images of stars look better slightly blurred because it can make the colors more noticeable. This repeats the classic observation, often rediscovered during public nights, that colorful binary stars sometimes look better in the finder scope than through the main telescope.

If you shoot stars low in the sky, their images can have red and blue parts that don't align because of atmospheric refraction. A *Registax* function that can

Rigel (Alpha [α] Orionis) is Orion the Hunter's brightest star and the seventh-brightest star overall. It shines at magnitude 0.12. Rigel B, to its lower right, shines at magnitude 7.

V More than 60 percent of all stars are double or multiple stars. Those stars appear as a single point to your unaided eyes but resolve into pairs or triplets through a telescope. Imaging double stars is fun, easy, and rewarding. Such astrophotography doesn't take a large telescope or a complicated setup, and you can observe them from within a city. Because of the various separations between components, there are challenging objects for every size telescope.

Iota Cassiopeiae

95 Herculis

Mesarthim (Gamma Arietis)

Algieba (Gamma Leonis)

Wezen (Delta Canis Majoris)

Vega (Alpha Lyrae)

Mirzam (Beta Canis Majoris)

Arcturus (Alpha Boötis)

^ To produce each of the star images in this story, the author shot between 1,000 and 2,000 frames of video. He then used software called *Registax* (www.astronomie.be/registax/) to select the best frames and sum them into a single image.

correct this is "RGN Align," under the "Wavelet" tab. I usually just click "Estimate" and let the program automatically determine where the centers of the red and blue images are. It shifts them together so they appear as they would if the star were near the zenith. Be careful not to shoot too low.

If the star lies within about 20° of the horizon, the images may be so distorted that RGN Align won't work. I also did not account for one other atmospheric effect. Dust in Earth's atmosphere makes celestial objects appear fainter and redder the closer to the horizon they lie. The colors shown here are slightly redder than the real objects.

Help complete the list

I look forward to seeing what other observers do. I have imaged the 50 brightest stars with declinations north of –30°. I took these images in just 3 nights. I am seeking collaborators in the Southern Hemisphere to get the rest. E-mail me at fringwal@csufresno.edu. As a project-oriented instructor, I'll probably move on to the 100 brightest stars, then the 200 brightest, then who knows? Webcam star imaging is easy and fun, and can open up the universe of astroimaging to you without breaking the bank.

Antares (Alpha [α] Scorpii) glows at magnitude 1.1. Because of its color and the fact that Mars often appears in its vicinity, Antares has the nickname "Rival of Mars."

Sirius (Alpha Canis Majoris)

W Orionis

Pollux (Beta Geminorum)

Dubhe (Alpha Ursae Majoris)

> These four stars illustrate the wide range of magnitudes and colors you can image with a webcam. Sirius (Alpha Canis Majoris) is the brightest of all nighttime stars. It glares white-hot at magnitude –1.47. Variable star W Orionis, on the other hand, reaches only magnitude 5.88 at brightest. Astronomers classify W Orionis as a carbon star. One characteristic of such stars is a deep-red color. Pollux's orange color puts its temperature between these two stars.

See more webcam star images on-line at www.Astronomy.com/toc.

Equipment review

Vixen's giant binoculars among largest sold

Use the BT-125-A, and you'll know why many observers love large binoculars. **by Phil Harrington**

Specifications

Vixen BT-125-A

Aperture: 4.9 inches
Prism type: BaK-4
Focal length: 760 millimeters
Focal ratio: f/6
Eye relief: 20mm
True field of view: 1.6° (with 30mm eyepieces)
Weight: 24 pounds (10.9 kilograms)
Price: $3,699 (binoculars only)
$3,999 (with two 22mm eyepieces [28x])
$4,399 (complete package)

No question about it: Binocular astronomy is growing in popularity. But merely looking through small, handheld models doesn't satisfy today's stargazers. We're just as aperture-hungry as telescope observers. And with good reason. Giant binoculars, with triple-digit apertures and magnifications of 20x or more, are among the most exciting instruments for viewing the heavens because they collect enough light to make objects easy to see, and they offer a wide field of view.

Setup and operation

Among the largest giant binoculars sold today are Vixen's BT-125-A. Recently, I had the opportunity to put them through their paces. I was not disappointed.

Assembly takes about 5 minutes. A captive bolt secures the fork-style alt-azimuth mount/half-pier combination to the tripod. Although the optical unit weighs 24 pounds (10.9 kg) — certainly on the heavy side for some people — a convenient handle between the barrels makes setup easy.

Two Teflon-wrapped metal axles extending from the binoculars' center of gravity nest into matching hinged clamps on the fork mount. Once the binoculars are in place, adjust the clamp pressure until the unit moves up and down smoothly (without swinging uncontrollably). Azimuth (left-right) motion was equally smooth after I turned a tension-adjustment wheel at the half-pier's base.

The binoculars are too long to swing through the fork without hitting its base. To aim them higher than about 45°, you first have to tilt the fork by loosening a setscrew at the center of the fork base and pivoting the arms. Angling them at 45° makes it possible to point at the zenith without hitting the mount. Although this shifts the center of gravity away from the tripod's center, it does not compromise the mount's stability. Because celestial objects look best when viewed through less atmosphere, I did most of my observing above the 45° threshold.

Phil Harrington *is a contributing editor of* Astronomy. *He is currently working on a new observing guide for challenging objects.*

Each front lens of the BT-125-A measures 4.9 inches (125mm) across. This allows a lot of light to reach your eyes, brightening objects that normally appear faint through binoculars. All photos: William Zuback: *Astronomy*

Optics

One look at the fully multicoated objective lenses (each a 4.9-inch f/5 doublet) and you know the BT-125-A means business. The greenish coatings in the test pair appeared flawless. When I shined a flashlight into the barrels, I saw no indication of manufacturing flaws, such as errant metal flakes or other quality-control issues. Dew caps extend 3.2 inches in front of each objective to guard against stray light and lens fogging.

Both eyepieces showed circular, fully illuminated exit pupils. This indicates that the Vixen prisms, made of superior BaK-4 glass, are the proper size for the optical design. If the exit pupils were asymmetric or showed a grayed, diamond-shaped edge, the prisms would not be able to deliver the full potential of the huge objective lenses.

Mechanics and engineering

As with all giant binoculars, the eyepieces focus individually. Focusing was simple to achieve and smooth. Neither helical focuser showed any hint of binding.

The 45° angled eyepieces sit in cylindrical prism assemblies that pivot, allowing observers to adjust interocular distance (the spacing between the two eyepieces) until both fields of view merge. The range of interocular adjustment varies from 57 to 73 millimeters. I

found viewing to be comfortable even while wearing eyeglasses, thanks to each eyepiece's generous 20mm of eye relief.

With 30mm eyepieces, the BT-125-A boasts a true field of view of 1.6°, which I confirmed during testing. Stars were pinpoints across all but the outermost edge of the field. Aiming the BT-125-A accurately proved tricky at first. Although the binoculars do not come with a finder, they do have a standard finder mounting base. Once I put my own finder scope into place, aiming became a breeze.

Under the sky

I clearly resolved stars in the bright globular clusters M3 and the Hercules Cluster (M13), while the distinctive disks of two planetary nebulae — the Dumbbell Nebula (M27) and the Ring Nebula (M57) — were both readily visible.

I also spotted the nebulous bridge connecting the Whirlpool Galaxy (M51) and its irregular companion, NGC 5195. I could even make out a hint of M51's distinctive spiral structure.

Targets closer to home also put on fine shows. Although I noted some residual chromatic aberration in the form of a purple fringe to the Moon, the impact of the faux 3-D effect that the Vixens created overshadowed that small defect.

Jupiter's equatorial belts and Saturn's rings were also clear, although 30x is not enough oomph to show fine planetary detail.

That's why I'm pleased Vixen's new version of these binoculars has interchangeable eyepieces. All BT-125-A models now work with any 1¼" eyepiece. That's a plus because some other binoculars work only with special eyepieces. I can only imagine what the views through these will be like with a pair of premium wide-field eyepieces in place. Wow!

Contact information

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San Clemente, CA 92673
[t] 949.429.6363
[w] www.vixenoptics.com

Vixen's BT-125-A binoculars weigh 24 pounds (10.9 kg). You can set the unit up in only a few minutes.

Eyepieces are interchangeable, and each focuses separately. Observers also can change the interpupillary distance, which is the separation between your eyes.

Webtalk

Bring the universe inside with Astronomy.com

When cold autumn winds blow you indoors, use www.Astronomy.com to view the night sky inside. "The sky this month" tunes you into the most observable events in the November sky. The interactive "Star Atlas" lets you zoom through full-color maps of the sky. Plus, find web extras that go deeper into November's printed articles.

November web extras

Web extras at www.Astronomy.com/toc bring you additional research, interviews, photographs, and animations that our editors turned up while creating the magazine stories.

"Are these space rocks from Mercury?" p. 32
Learn how to tell an ordinary rock from a meteorite.

"How scientists discovered a solar system 'super highway' " p. 38
See an animation of a telescope's journey on the IPS.

"Ask Astro" p. 56
Could an observer on Mars watch Earth and the Moon transit the Sun?

"Where the northern lights dance" p. 62
View more of the author's auroral images.

"Calling on Cassiopeia" p. 76
Phil Harrington continues exploring Cassiopeia the Queen.

NGC 896 and IC 1795 glow in Cassiopeia.

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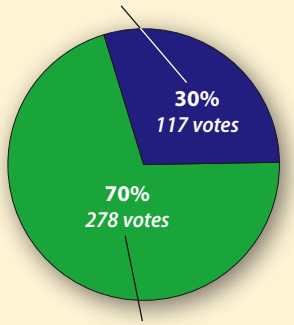
Online poll results

Will the May-June 2010 Endeavour mission be the last space shuttle flight?

Yes, NASA will retire the shuttle and begin using the next generation vehicle soon thereafter.



No, the next generation vehicle will not be ready for years. Commitments will force NASA to use the shuttle.

Total votes: 395

Join the fun! You'll find the weekly question on the lower right side of the home page.

MESSENGER at Mercury

This month's top blogs

Listen to our weekly podcast on-line or download it for later at www.Astronomy.com/podcast. Shows range from scientific breakthroughs to constellation tours to book reviews, and more.

1 BACK IN THE SADDLE
Scott Roberts, formerly of Meade Instruments, returns to telescope manufacturing with the launch of Explore Scientific.
BY JEREMY McGOVERN

2 INTRODUCING NASA'S "LONE GUNMEN"
A group of dissident engineers and managers are anonymously designing a better, safer, and cheaper version of the Ares I. **BY DANIEL PENDICK**

3 THE ASTRONOMICAL LEAGUE ACKNOWLEDGES WEBMASTERS
Del Gordon of the Huachuca Astronomy Club was the first place winner of the group's annual contest. **BY JEREMY McGOVERN**

Ares I

It's showtime!

Visit www.Astronomy.com/videos for our exclusive videos that share how-to tips, explain science headlines, showcase equipment, and more.

Featured video

SEEING SUNSPOTS ON OTHER STARS
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Observing Basics

by Glenn Chaple

Clearing the air about seeing *vs.* transparency

Read this and you'll understand what keeps you from seeing celestical objects clearly.

Susan bought a telescope. Not just any fly-by-night model, mind you, but an expensive, high-tech instrument. On the first cloudless night, she aimed the scope at Jupiter, peered into the eyepiece, focused, and … ack! What's this? All she saw was an undulating blob of light. Susan was understandably frustrated and considered returning the telescope for a refund.

It wasn't the scope. Susan would soon learn that the finest optical instruments in the world play second fiddle to that fickle element that starlight first encounters: Earth's atmosphere. The ever-changing ocean of air surrounding our planet can be calm or turbulent, clear or murky — dramatically affecting what we ultimately see at the eyepiece.

The steadiness of our atmosphere is known as "astronomical seeing." Good seeing is paramount for sky objects that require high power, like the Moon, the planets, and narrowly separated double stars. If the air is calm, you can use the maximum possible magnification your telescope will allow. Throw in some atmospheric turbulence, however, and you'll experience what Susan saw the night she christened her telescope.

A slew of factors contribute to seeing conditions, from global weather patterns to air currents inside the tube of a telescope that hasn't yet adjusted to the outside temperature. Heat waves rising from the ground after sunset or from dwellings on cold evenings can also produce annoying ripples.

Of the various scales devised to rate seeing, I find the 1 (terrible) to 5 (ideal) particularly useful for basic backyard astronomy. You can get a "ballpark" estimate of seeing simply by looking up and noting how rapidly stars twinkle.

A more precise way to assess seeing conditions is to look at the image of a bright star under high magnification. If it "boils" incessantly, rate the seeing as 1. If the image is crisp and surrounded by unwavering concentric circles (diffraction rings), the seeing is a 5.

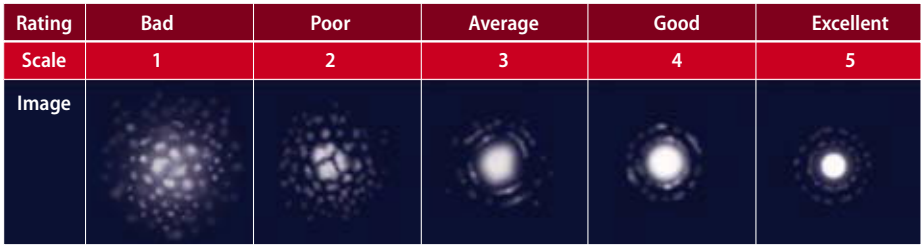
The term "transparency" describes the night sky's clarity and darkness. Hazy skies are the products of atmospheric water vapor (common on warm summer nights) or impurities like smoke, dust, or pollen. Even if the night air is clear and dry, stray light from the rising or setting Sun, the Moon, or annoying artificial light can compromise transparency.

A simple way to evaluate transparency is to gaze at a portion of the sky roughly halfway up from the horizon and note the whole number magnitude of the faintest star visible. This produces a scale from 0 (totally overcast) to 6 (the faintest star traditionally visible from a dark-sky location). In remote areas, the scale can even extend beyond 6. If you rate the transparency as 7 or even 8, you're in the Australian Outback, mate!

The angle above the horizon of the object you're observing also affects seeing and transparency. From the zenith (overhead) to the horizon, transparency decreases (atmospheric extinction) because you're looking through a thicker column of air. Seeing similarly suffers.

It's an astronomical fact of life that good seeing and transparency rarely go hand-in-hand. A night of exceptional seeing is often accompanied by poor transparency, and vice versa. In mid latitudes, we experience some of the best seeing during the warm, hazy nights of summer, while cold winter evenings bring transparent, but often turbulent, skies. During the transition periods of spring and fall, we can get a delicious mix of either.

Whatever the season, you'll want to learn to evaluate the sky conditions and then adapt. If the seeing is good, target the Moon and planets or that close double star you've never been able to notch. Transparent skies give you a chance to ferret out faint galaxies or nebulae.



Astronomy: Jay Smith

This chart shows what a point source looks like through a telescope under different "seeing" conditions. When the atmosphere is unsteady, the star's image becomes larger and more blob-like.

From our great ideas department comes a suggestion from Joe Shuster of Gurnee, Illinois. In reference to my article on astronomical awards in the April 2008 issue of *Astronomy*, he writes: "I think it's more fun giving awards than getting them." His club, the Lake County Astronomical Society, presents "Lake Sky Star Awards" to non-astronomers who do things that promote astronomy. When a car dealership agreed to temporarily reduce its lighting so it wouldn't disrupt the society's star party at a local school, the club gave the dealer an award.

For more information, go to www.lcas-astronomy.org, and click on "Lake Sky Star Awards."

Binocular Universe

by Phil Harrington

Calling on Cassiopeia

Here's where to find Cassiopeia's most exciting binocular targets.

Last month, we visited the sky king, Cepheus. This time, we pay a call on his wife, Cassiopeia. For us devout binocularists, she is more than just a mythological queen of ancient Ethiopia; she is the queen of the autumn sky. Cassiopeia harbors a bevy of celestial beauties to hunt down and enjoy.

Let's begin with the Double Cluster, a stunning pair of open clusters nestled right next door to each other. The Double Cluster is one of autumn's most spectacular binocular attractions. Although the clusters technically lie just across the border in Perseus, you can easily locate them by following a line from Gamma (γ) Cas through Ruchbah (Delta [δ] Cas) and continuing southeastward.

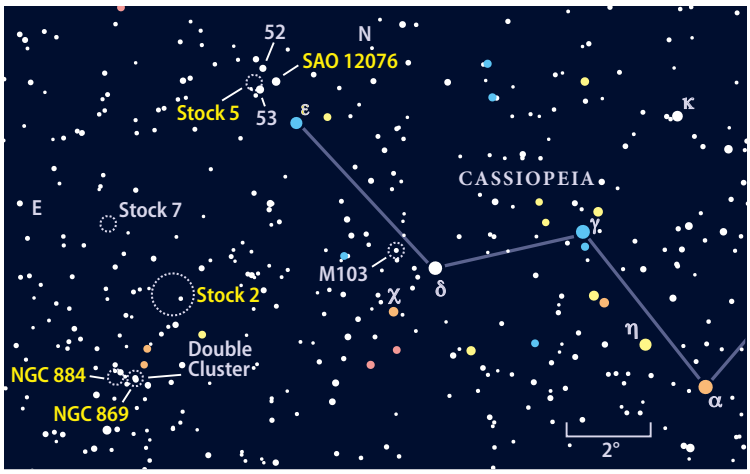
Through 10x binoculars, the Double Cluster dissolves into two tightly packed groups of stars floating against a strikingly beautiful field of background stars. Each cluster contains just over 300 stars, although **NGC 869**, the western member in the pair, appears more densely packed. Most of the stars in NGC 869, as well as those in the eastern cluster, **NGC 884**, appear either white or blue-white. But don't be surprised if you also see a few yellowish suns poking out from the crowd.

Most observers become so entranced with the Double Cluster that they don't even notice another open cluster in the same binocular field. You're not alone; this neglected cluster is not included in the Messier or NGC lists. Instead, it carries the designation **Stock 2**, the second entry in Jürgen Stock's 1956 catalog of more than 20 suspected open clusters.

To find Stock 2, follow the arc formed by about a half dozen magnitude 6 and 7 stars trailing from the Double Cluster to the northwest. Look just north of the arc's end for a rectangular swarm of faint stars that's elongated roughly east-west. It can't compete with the Double Cluster, but Stock 2 is still fun to look at, especially on dark nights.

Don't just glance at Stock 2 quickly; take a good look at its stars. See anything? Massachusetts amateur astronomer John Davis was the first to note, more than 20 years ago, that the brighter cluster stars, along with a few unrelated field suns, form a headless stick man flexing his muscles.

The muscleman's body extends due east-west, while his legs appear as two faint strings of stars continuing farther east. Two arcs of stars branch off to the west to form his flexed arms, completing the picture. Most of the muscleman's stars shine between magnitude 8 and 9, which puts them right on the edge of visibility through 50mm binoculars. Larger apertures should be able to fill in the figure fairly easily.



Cassiopeia's star clusters are worthy binocular targets. *Astronomy:* Jay Smith

Stock 5 is located about 1° northeast of the star **Segin** (Epsilon [ε] Cas), the easternmost star in the Cassiopeia "W." Look for a V-shaped asterism of stars, which reminds me of an in-flight gaggle of geese. The magnitude 5 star **SAO 12076** leads the way, followed by 52 and 53 Cas as well as a few fainter goslings. Adding three dim suns just east of 53 appends a diamond pattern to the end of the flock.

Three of the diamond's stars, including 53 Cas, along with another 20 or so fainter suns, collectively form the open cluster Stock 5. Although the cluster stars are loosely packed, you might detect a slightly hazy quality to that diamond, especially if you are viewing through binoculars with 12x magnification or greater.

Lastly, scan about 8° (a little more than a binocular field) northward from Segin to a keystone of four stars formed by 40, 42, 48, and 50 Cas. Take a careful look inside the keystone for a dim glow. That's another little-observed open cluster, **Collinder 463**. (Not shown on map.) Spanning an area of sky equal in size to the Full Moon, Collinder 463 is made up of 79 faint stars lying some 2,100 light-years from Earth. The brightest shine between magnitudes 8 and 9.

The Queen has plenty more in store for binocular observers this month, so drop by *Astronomy.com* to continue your tour. Meanwhile, remember that two eyes are better than one.

Continue exploring Cassiopeia the Queen at Astronomy.com/toc.

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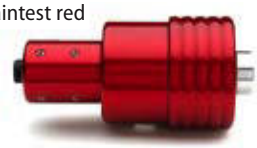

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2. Entry. There will be two categories, one for students in grades 6-8 and one for students in grades 9-12. Students must work together to create a video on their specific topic. For students in grades 6-8 the topic is "Pluto: Planet or not?" and for students in grades 9-12 the topic is "What is a black hole?". Videos can be no longer than three minutes in length with the final product provided for judging on DVD format. Groups with a maximum number of four students can produce this video with the assistance of a teacher only serving as an advisor. No professional assistance can be provided to produce this video in any manner. All students must be from the same school. Students are responsible to provide their own equipment, or use the schools, to produce this video. One entry per group. The information, facts and figures that appear in the video must be researched by the students and documented. If a student plans to appear in the video and is under the age of 18, a parent/guardian is required to complete a video permission slip. During the video the name of the school cannot be mentioned. First names are allowed only of the students appearing in the video. Each entry must be accompanied with an application correctly completed along with signed releases. Applications will be made available on Astronomy.com. Videos cannot contain any objectionable content and there can be no plagiarism of songs or videos. Videos will be judged on accuracy, achieving goal for the topic specified, clarity of concept presented, video and audio quality and creativity. The decision of the judges will be final. The videos become the property of *Astronomy* magazine and are not returnable. Videos must be submitted on a DVD playable in Window Media Player or QuickTime. Videos that do not meet the above requirements will be disqualified.

To enter, teacher/advisor must pre-register by filling out the form with as much information as they have available prior to submitting a video to: The Young Astronomers Video Contest, P.O. Box 378, Waukesha, WI 53187-1199. A completed form must also accompany the video project with all the necessary waivers signed. The form must be filled out completely to be eligible. Downloadable forms can be found at Astronomy.com. Incomplete or defaced entry forms are void and the entries will be disqualified. Videos must be received by 11/7/08. Entries received after that date will be disqualified. The top five entries will then be available for viewing on Astronomy.com by 12/5/08 where visitors to the Web site will vote for the winner. The official ending date for 12/19/08 will be and a one winner from each category will be announced by 12/29/08.

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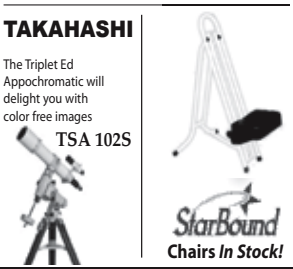
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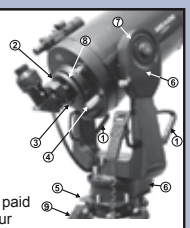

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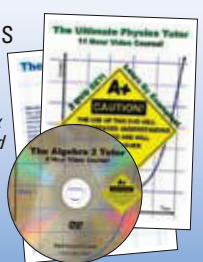

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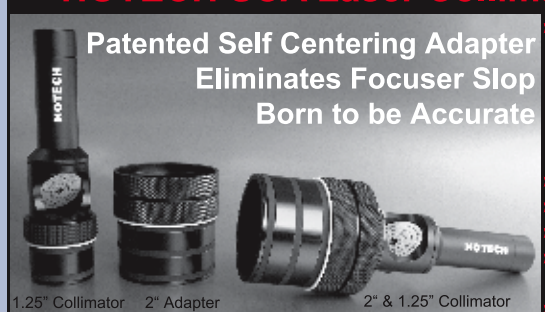

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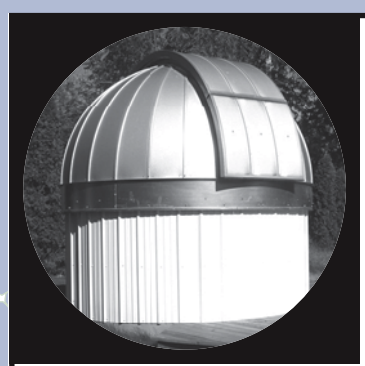

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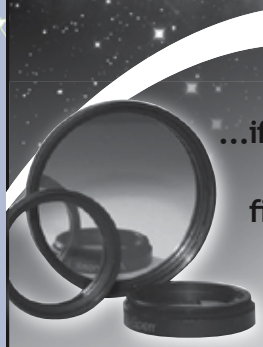

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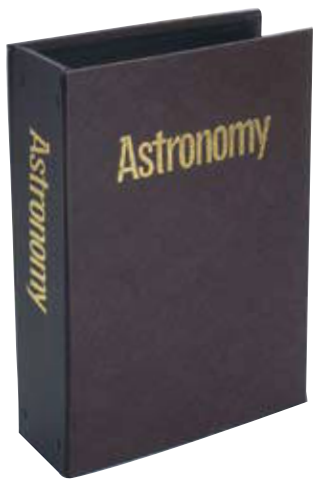

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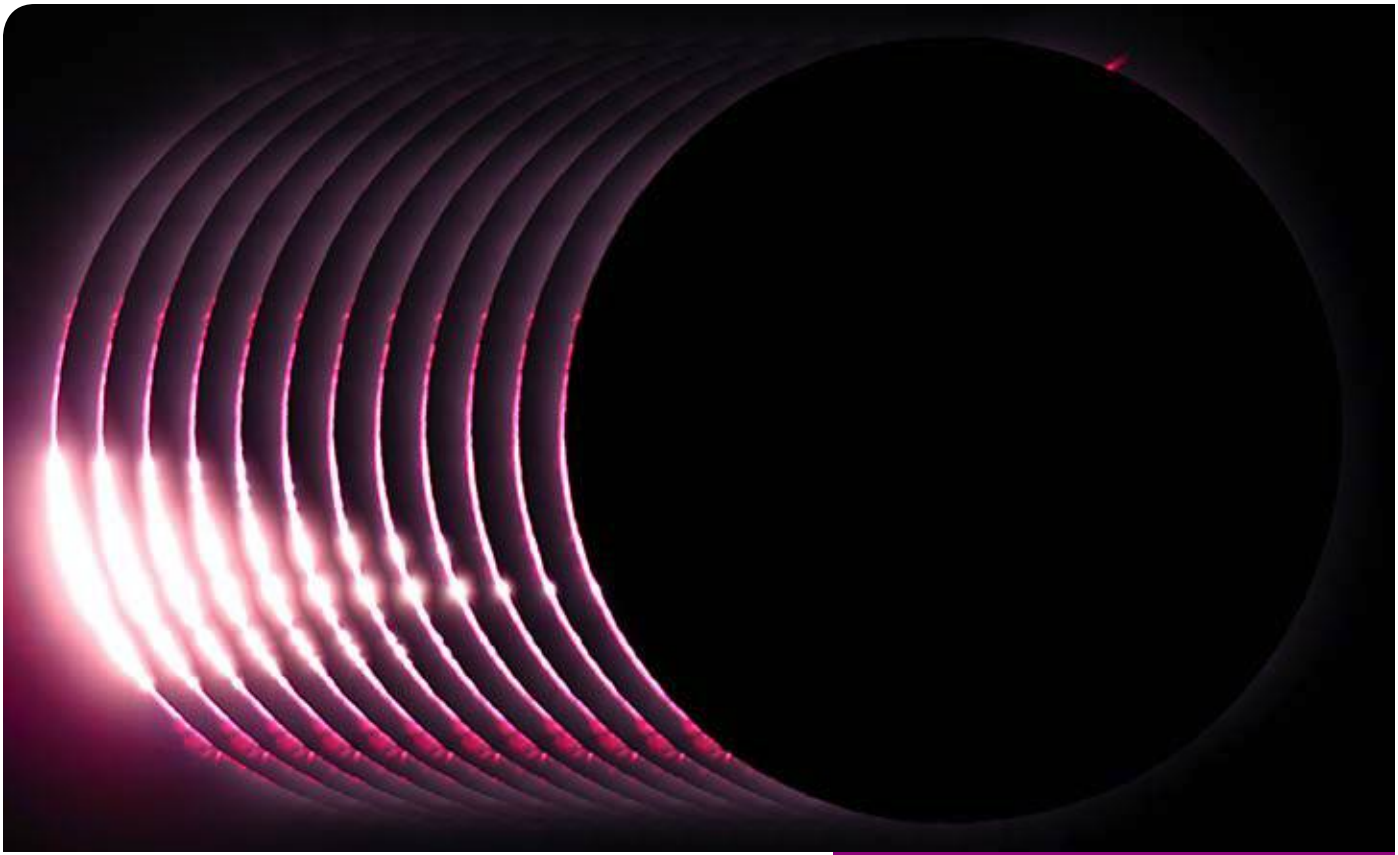
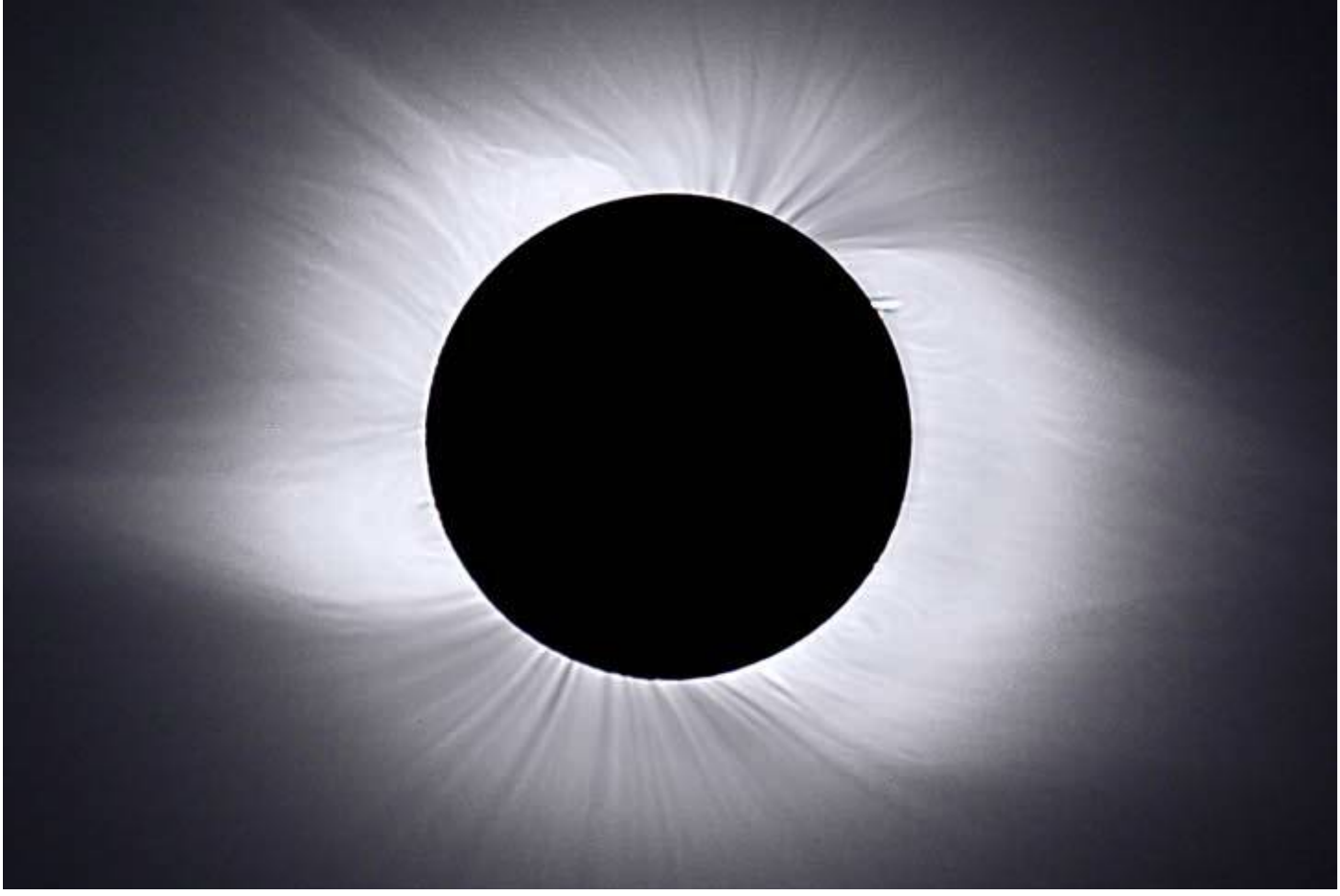


The 5 seconds before totality revealed a phenomenon called Baily's beads — tiny beads of sunlight shining through irregularities along the Moon's limb. (8-inch Meade LX10 Schmidt-Cassegrain telescope at f/10, Hutech-modified Canon EOS 5D digital SLR, ISO 400, 1/1,600-second exposures) • Tunç Tezel, Bursa, Turkey

"Diamond ring!" cries erupted from all over the observing field as the Moon covered the last brilliant segment of the Sun's disk. (4-inch Takahashi FSQ 106 apochromatic refractor at f/5, Canon EOS 350D XT digital SLR, 1/500-second exposure) • Anthony Ayiomamitis, Athens, Greece

The Moon covers the Sun

Every so often something spectacular happens in the daytime sky — a total solar eclipse. This event marks the exact alignment of the Sun, the Moon, and Earth. If the Moon's disk appears larger than the Sun's, our natural satellite will blot out the Sun. The Moon's dark inner shadow then will make a thin path across Earth's surface. Those lucky enough to be on that line see totality. On August 1, astroimagers in Novosibirsk, Russia, imaged the most recent total solar eclipse whose totality lasted a scant 2 minutes, 18 seconds.



^ The Sun's corona appeared rectangular to the unaided eye as totality hung in the clear sky. (4-inch Takahashi FSQ 106 apochromatic refractor at f/5, Canon EOS 350D XT digital SLR, 15 combined exposures from 1/15- to 1/500-second) • Anthony Ayiomamitis, Athens, Greece

< One red prominence (at the 1 o'clock position in this image), visible through binoculars and telescopes, fascinated eclipse viewers in Novosibirsk, Russia. (8-inch Meade LX10 Schmidt-Cassegrain telescope at f/10, Hutech-modified Canon EOS 5D digital SLR, ISO 400, 1/2,000-second exposure) • Tunç Tezel, Bursa, Turkey

v The August 1 eclipse lasted for about 2 hours, as captured in this sequence. Unfortunately, the most dramatic part — totality — flew by in 2 minutes, 18 seconds. (Nikon D200 digital SLR, 400mm lens at f/5.6, ISO 200, 1/250-second filtered exposures for the partial phases, 1/2,000-second unfiltered exposures for the diamond rings, and 1/30-second unfiltered exposure for totality) • Ben Cooper, Daytona Beach, Florida

reader gallery

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From the edge of the Ob Reservoir in Novosibirsk, Russia, the eclipse occurred in a cloudless sky, thrilling all 500 viewers who had gathered to see it. Photographer Ben Cooper took exposures every 5 minutes to create this sequence. This technique not only captured the drama of the event, it also showed how clear the sky was during the eclipse. (Nikon D70 digital SLR, 17mm lens, ISO 200; partial phases: solar filter, f/5.6, and 1/250-second exposures; totality: filter removed, f/8, and a 1.5-second exposure) • Ben Cooper, Daytona Beach, Florida

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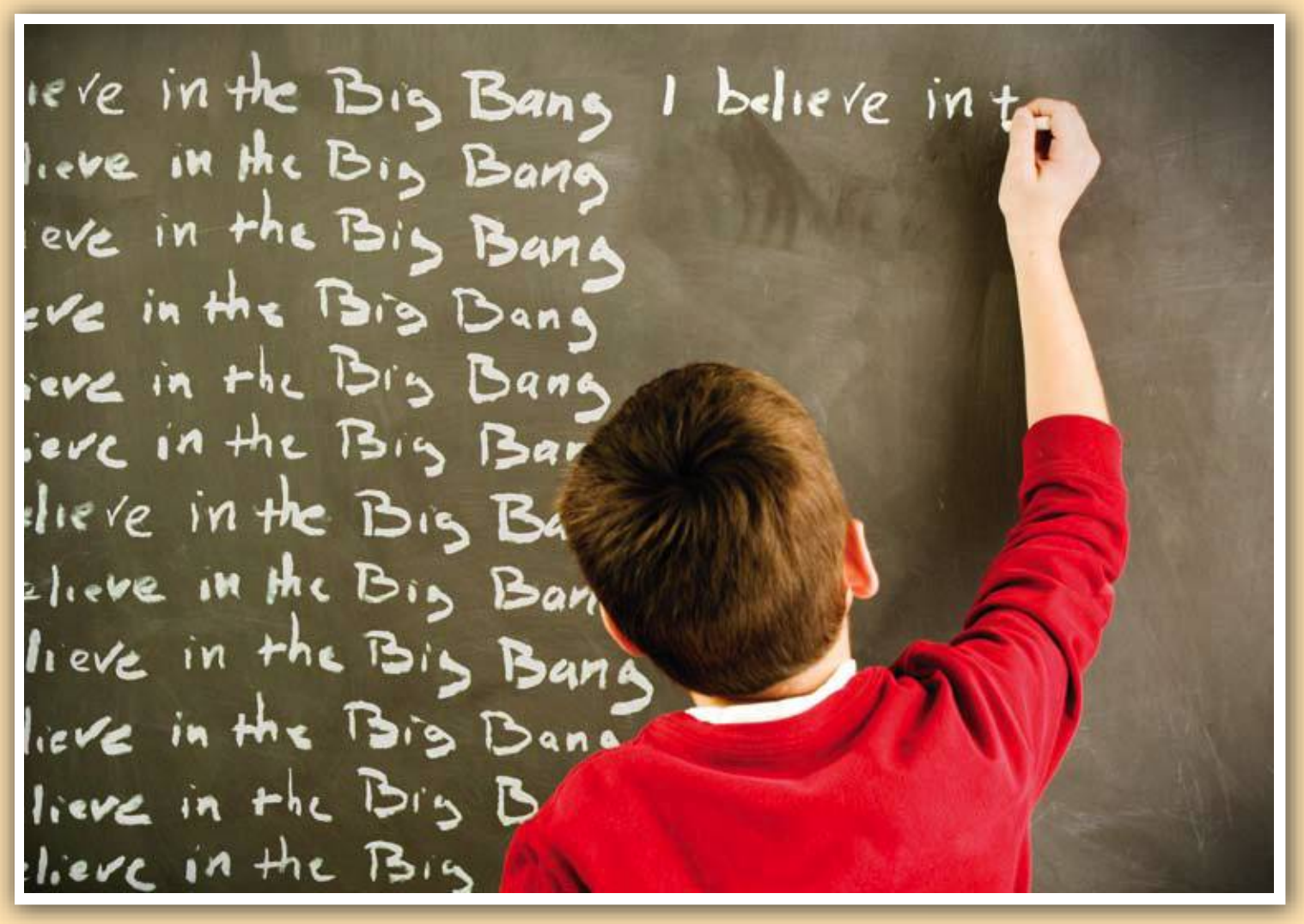

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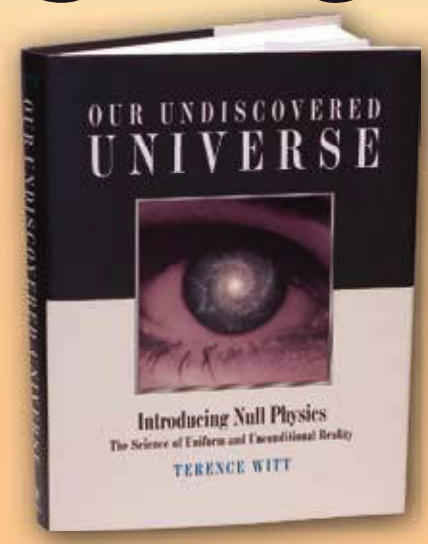

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